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ADVANCED WELDING TECHNOLOGY FOR METAL FABRIC

J. E. Crawford

Aerojet-General Corporation
Space Division

TECHNICAL REPORT AFML-TR-69-312

October 1969

Air Force Materials Laboratory
Air Force Systems Command
Wright-Patterson Air Force Base, Ohio

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FOREWORD

This Final Technical Report covers all work performed under Contract AF33615-68-C-1545 from April 1968 to August 1969. The manuscript was released by the author in November for publication.

This contract with Aerojet-General Corporation, Space Division, El Monte, California, was initiated under Manufacturing Methods Project 805-8, "Advanced Welding Technology for Metal Fabric". This work was administered under the technical direction of Mr. Frederick R. Miller of the Fabrication Branch (MATF), Manufacturing Technology Division, Air Force Materials Laboratory, Wright-Patterson Air Force Base, Ohio.

Mr. J. E. Crawford was the Principal Investigator and Program Manager for this program. Other Space Division technical personnel which contributed to the program are:

Mr. J. F. Keville
Mr. R. R. Lewis
Mr. A. Speyer
Dr. J. A. Wrede

This project has been accomplished as part of the Air Force Manufacturing Methods Program, the primary objective of which is to develop, on a timely basis, manufacturing processes, techniques and equipment for use in economical production of USAF materials and components.

Your comments are solicited on the potential utilization of the information contained herein as applied to your present and/or future production programs. Suggestions concerning additional manufacturing methods development required on this or other subjects will be appreciated.

This technical report has been reviewed and is approved.

G E Eichelman
GAIL E. EICHELMAN
Acting Chief, Fabrication Branch
Manufacturing Technology Division

ABSTRACT

Many advanced systems require flexible, high-strength structural materials capable of operating at environmental temperatures up to 2000°F in order to efficiently perform the required system missions. This is especially true of inflatable, pressure stabilized structures for space and reentry applications, and non-flammable components and systems for manned space flight. Highly efficient metal fabrics have been developed to satisfy these material requirements but no efficient method of joining these materials into flexible structural configuration was available until a unique automatic spot-welder for producing flexible joints in fabrics was developed by the Aerojet-General Corporation under a previous contract for the Air Force Materials Laboratory. The work reported herein explored the capabilities of this joining technique for application to a wide variety of nickel-chrome structural fabric styles, and is probably equally as efficient for fabrics woven from other steel alloys. Good, flexible, structural joint properties were found up to the 1000°F limit of the test temperatures.

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SECTION I

INTRODUCTION

Current space systems and hypervelocity flight in the atmosphere require the use of expandable structures capable of being pre-packaged in a small volume for subsequent deployment into highly efficient structural configurations capable of supporting high internal and external loads, often during exposure to high temperatures or the severe environment of space. Astronaut suits, reentry paragliders, hypervelocity drag chutes, large space antennas, high temperature fuel cells, and radiation resistant structures are examples of these types of structures.

Metal fabrics woven from super alloys provide a highly efficient material for these structures. These metal fabrics were made practical through the development of single and bundle drawing techniques that yielded 0.5 mil superalloy fibers by the Fibrous Materials Branch of the Air Force Materials Laboratory. However, the joints must be flexible, structurally efficient, and as resistant to the environment as is the parent fabric. The spot-welded, flexible joint system developed by the Space Division of Aerojet-General Corporation, under a previous Air Force Contract, demonstrated the feasibility of this system, utilizing one particular metal fabric, for the structure of a large reentry paraglider.

The objective of this program was to broaden the scope of this technology to establish the capabilities and limitations of this welding system when utilized on a wide variety of lighter weight, more flexible metal fabrics woven from even smaller filaments, and to compare the efficiency of this joining system with other joining methods. After the exploratory development was completed, testing of qualification coupons was conducted to establish the physical characteristics of the fabric joints at room and elevated temperature, as well as the effect of creasing and folding on the joint efficiencies.

This report contains a review of all the technical effort of this program, including the refurbishment of the experimental welder. The results of this program demonstrate that the flexible joint spot-welding system is adaptable to a wide range of types of metal fabrics and can reliably produce highly efficient joints in these ultra-fine filament metal fabrics.

SECTION II

SUMMARY

The objective of this specific program was to analytically and experimentally investigate the welding parameters and limitations associated with the welding of flexible joints in various metal fabric styles woven from 0.5 mil diameter Chromel R filaments. The spot welded fabric joint efficiencies, crease resistance, fold endurance, and tensile strengths, were established for single and multi-drawn filament fabrics and also for comparison with sewn seams, at room temperature and 1000°F.

These ultra-fine filament, thin metal fabrics have a high ratio of surface area to volume and are therefore more susceptible to degradation from oxidation, forging pressures and fusion rates. As the experimental spot welder had produced several million welds, certain repair work and corrective maintenance was required. The initial project efforts were concentrated on the disassembly of the welder, and the detailed and rigorous inspection and analysis of the mechanism condition in order to determine the fundamental modes of failure.

2.1 WELDER REFURBISHMENT

The initial program task required the refurbishment of the experimental welder that was developed under Air Force Contract AF33(657)-10252. This welder had produced several million welds in metal fabric woven from one mil filament yarns, with joining efficiencies in excess of 89% relative to the parent fabric strength. A number of components of the welder required replacement or reworking. Subsequent check-out of the welder revealed that high quality welding was critical relative to clearances and friction in the electrode plungers, as well as electrode alignment, fabric cleanliness and other processing parameters.

The refurbishment was successfully completed and average spot-welded joint efficiencies, in all fabrics tested, was increased to consistently over 91%.

The primary problems were found to be related to the upper weld head mechanism, weld head shaft and splines, and the power supply programmer. Some minor redesign eliminated the shaft and spline friction and alignment problems. The weld head mechanism was reworked in detail to reduce clearances and friction that contributed to chatter and alignment problems.

The automatic welding sequencing system was instrumented to analyze the timing and sequencing of events. A five millisecond overlap of events was revealed that caused initiation of fabric advance prior to the electrode retract signal. The programmer wafer switch was rewired and the sequence-time overlap was eliminated.

The welder now performed very efficiently and reliably at rates in excess of 640 spots per minute (8.0 inches of seam per minute), although most welds were run at 3.5 inches per minute due to the difficulty in handling small coupon size pieces of fabric. The typical welded seam consisted of two rows of 0.015 inch diameter spot welds with 40 spots per inch in each row. The rows are 0.30 inches apart.

2.2 METAL FABRICS

Five GFE metal fabrics were utilized for the welding experiments. The Chromel R and Karma filament alloys were 20% chromium and 74% nickel with small percentages of aluminum, iron, silicon and carbon. Typical room temperature ultimate strengths for the fully annealed single drawn filaments is 185,000 psi. At 1000°F this strength is reduced by approximately 2%, and at 1200°F by 20%. One type of 0.5 mil diameter filaments tested was experimentally produced by a low-cost method of drawing 100 filaments at a time. This process produced a useable fabric, but of considerably less strength than that of similar single drawn filament fabrics. The strength of this parent fabric was reduced by 20% at 1000°F.

One fabric, produced under a previous Aerojet-General Corporation program, was constructed from 1.0 mil Karma filaments, plied into 49 filament yarns and woven into a 2x2 basket weave fabric with 58 yarns per inch in each direction. The other four fabrics were woven by Fabric Research Laboratories under the technical direction of the Fibrous Materials Branch, Nonmetallic Materials Division, AFML (Ref. 3), and constructed of 0.5 mil Chromel R filaments plied into yarns and woven into two plain weave and two basket weave fabrics covering a range of fabric densities, strengths and weights from 10.2 ounces per square yard and 106 pounds per inch average tensile strength to 19.9 ounces per square yard and 247 pounds per inch. The 1.0 mil filament fabric was 27.4 ounces per square yard with an average tensile strength of 345 pounds per inch.

2.3 WELDING DEVELOPMENT

Welding parameters evaluated included variations in:

a. Voltage

b. Weld pulse duration

c. Electrode force

d. Welding speed

e. Transformer tap settings

f. Spot spacing

g. Electrode diameter

After extensive investigation of the influence of each of these parameters it was determined that the weld quality was relatively insensitive to the type of fabric, or combination of fabrics being welded, for nominal settings of the welder. The maximum range of required voltages varied from 158 to 165 volts. Weld pulse duration of 5 ms and an electrode force of 11.0 pounds appeared to be optimum for all test conditions. Welding speed is typically limited by practical problems of feeding the fabric seams into the welder, but good joints were produced at rates up to eight inches per minute. Variation in electrode diameters of 0.035, 0.050, and 0.065 inches also produced no discernible effect on the weld nuggets.

Spot weld spacing is primarily critical relative to joint strength and flexibility. The loosely woven 39 x 39 plain weave fabric yarns were so widely spaced that the electrodes frequently fell between yarns which indicated that the number of spot welds per inch would have to be increased to approximately 80 per inch per row. This close spacing of welds would have resulted in an essentially rigid joint. A better solution was developed that produced high joint efficiencies by simply adding a third row of welds to the standard two rows.

A total of 722 welded coupons were tested during this welding development phase of the program. After welded joint efficiencies in excess of 91% had been consistently achieved, preparation of Qualification Test Coupons was initiated.

2.4 QUALIFICATION TESTING

Five welded coupons of each fabric style, and one fabric combination, as well as coupons of the multi-drawn filament fabric with sewn seams were tensile tested at room temperature and 1000°F, and after sharp edge creasing, at room temperature and 1000°F. Additional coupons were tested for folding endurance both along and across the seam.

The Fabric Research Laboratories, Inc., under contract to Aerojet-General Corporation, prepared the sewn seam coupons and conducted the testing of most of the Qualification Test Coupons. Aerojet-General Corporation also conducted thirty room temperature tensile tests of Qualification Test Coupons on one set of five each of the welded joint and sewn joint fabric combinations. A total of 140 Qualification Test Coupons were tested.

It is important to note that the parent fabric strength typically varies by less than ±10% from average, but some materials tests produced failures as low as 14% below the test coupon population average. However, for the purpose of computing joint efficiencies, relative to the parent fabric strength, the parent fabric <u>average</u> rupture load is used.

The 70 spot welded Qualification Coupon tensile tests at room temperature produced an average joint efficiency of 96% for both the single lap joint and double lap joint fabric combinations tested.

Spot welded coupons tested by the Fabric Research Laboratories, Inc., after sharp edge creasing along the weld line, produced a reduction in joint strength due to creasing of less than 6% for four fabrics, at all temperatures tested and 10% reduction for the multi-drawn filament fabric at 1000°F. The combination of the 55 x 55 fabric joined to 39 x 39 fabric showed an unexplainable, apparent strength loss of 19% after creasing.

The only parent fabric tested at 1000°F under this contract was the 80 x 81 bundle-drawn filament fabric. The joint efficiencies for these fabric joint coupons are based on the parent fabric average strength at 1000°F. The spot welded coupons show only a 4% joint efficiency loss at 1000°F. The joint efficiencies for the other welded fabrics tested at 1000°F were calculated based on the room temperature average strength of the parent fabric, which indicated an apparent tensile strength loss of welded joint coupons, ranging from 5% to 18%. Without further test data it cannot be determined what portion of this strength loss is due to temperature degradation of the fabric, variation of parent fabric strength, or what portion is strength degradation attributable to the fabric joining processes.

Fold endurance across the spot welded seams was essentially identical to a single layer of parent fabric. However, the fold endurance along a welded seam was only an average of one-fourth of that of a single layer of parent fabric.

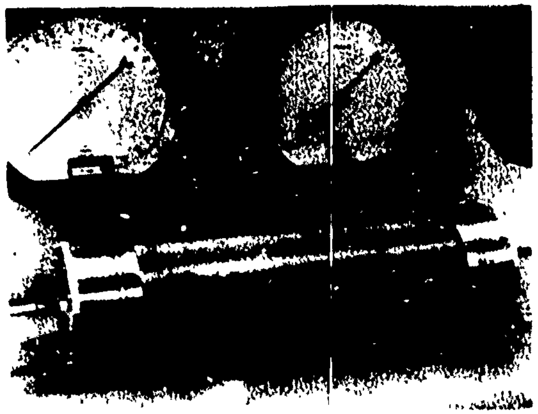
The sewn, seamed coupons had four layers of fabric in the joint and four rows of stitches. These coupons failed at an average rupture load 13% below that of the spot welded joint coupons, at room temperature and 1000°F, whether creased or uncreased before tensile testing. However, the fold endurance of these joints was excellent and approximated the endurance of four layers of parent fabric. (Published data for sewn joints for the other fabric styles indicates joint efficiencies comparable to spot welded joints for most fabrics.)

Statistical analysis based on a population of the five qualification test coupons of each configuration tested at AGC showed that the welded joint strength of seven of the eight fabric combinations, of two and four layer joints, exceeded 90% of the average parent fabric strength at the 90% confidence level, and ranged as high as 97%. Based on the original goal of an 85% joint efficiency, the confidence level that these joints will exceed that efficiency, based on the average parent fabric strengths, ranges from 99.3 to 99.95% for the various fabric combinations. The eighth fabric combination was computed to develop a 93% confidence level for the latter case (see Section 3.7 comments).

Statistical analysis of the sewn coupons showed that, for the one fabric tested, the two layer joint exceeded 79% of the average parent fabric strength at the 90% confidence level and a 64% of exceeding 85% of the average parent fabric strength. However, as previously noted these sewn joint efficiencies may be abnormally low.

2.5 DEMONSTRATION CYLINDER

A cylinder was fabricated from the 1.0 mil Karma fabric with welded fabric seams, and was internally sealed with silicone to provide a pressure stabilized structure to demonstrate the flexibility and structural integrity of this structural material system. Figure 1 shows the cylinder in various folding and packaging configurations. The calculated burst pressure for this cylinder is 107 psig.



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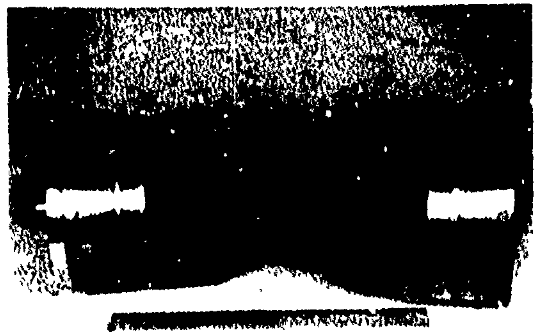
Cylinder Pressurized



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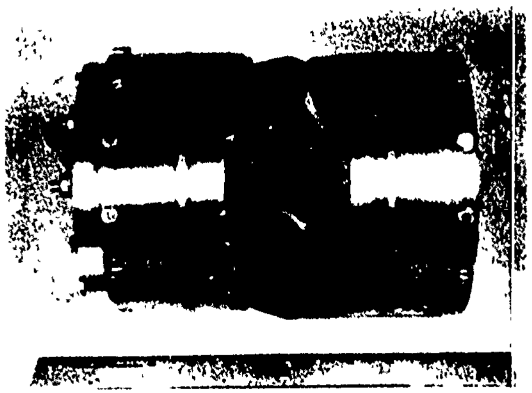
Cylinder Twisted



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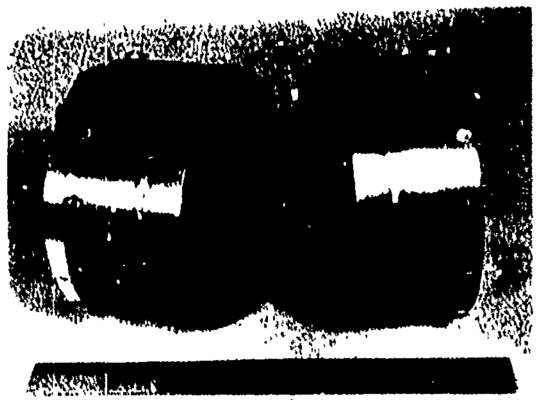
Random Folds



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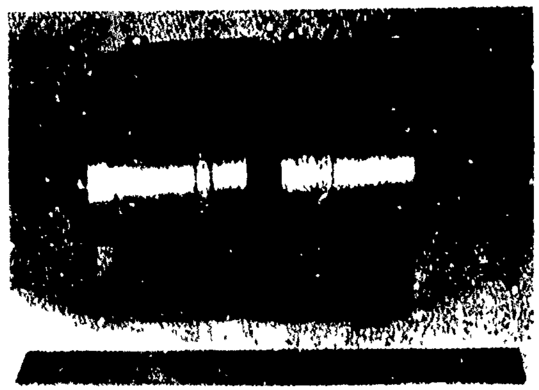
Twisted and Partially Collapsed



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Fabric Stowed Within The End Fittings

Figure 1. Demonstration Cylinder

SECTION III

DETAIL DISCUSSION

3.1 WELDER DESCRIPTION

The semi-automatic spot welder utilized during this program was developed under a previous Air Force contract. The welder provides for the precise, incremental spacing of two rows of miniature spot welds, with automatic feed of the fabric accomplished by rubber tire drive wheels. Directional alignment of the fabric, and fabric seam overlap is manually controlled.

The completely assembled welder with the bottom of the L-shaped arm in place is shown in Figure 2. To the left rear of the photograph is the center welding arm. The small, portable, Duffers current analyzer is shown in the center of the picture (rear). This instrument indicates either peak or rms amperage in the secondary circuit for one pulse, or continuously, and also is capable of counting pulses. Mounted on the right rear of the machine is the General Electric size 3, square-pulse power supply. Above this is the Space-Division-designed and constructed electro-mechanical sequence timer. A foot pedal is brought to the forward end of the machine so that the operator can control the speed of operation. The welder with the center arm in place is shown in Figure 2.

The lower and center support arms are interchangeable enabling the welder to accommodate all possible shapes of complex structures. The lower arm could be used for toroidal or cup-shaped objects; the horizontal arm would be used for structures generally of cylindrical or conical shape.

For making hoop seams or seams at orientations other than axial to the machine, the weld heads may be rotated in the horizontal plane to 24 different angular positions as determined by splined shafts and bushings incorporated in the support. The upper head is raised by use of the cam handle shown in Figures 2 and 3. The upper head is turned and lowered into the spline engagement position desired. The lower head angle is changed by loosening the lower nut so that the entire weld head can be raised clear of the splined parts and then turned and dropped into the desired position. It follows, of course, that both of the heads must be turned to the same angle so that the drive wheels are in the same plane when welding.

The sequencing timer control performs the functions of advancing the fabric, lowering one electrode, initiating a weld pulse, raising the electrode, lowering the second electrode, triggering another weld pulse, and concluding the cycle with raising of the second electrode. The overall welding speed is variable with the foot control from zero to approximately eight inches per minute. Each spot weld pulse must be of the same duration and, therefore, the weld pulse time period is controlled to a preset value by the power supply itself. The remainder of the time cycle is regulated by the rotational speed of a wafer or commutator-type switch driven by a small motor. The speed is regulated by a second braking motor regulated by the foot control.

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Figure 2. Completely Assembled Welder

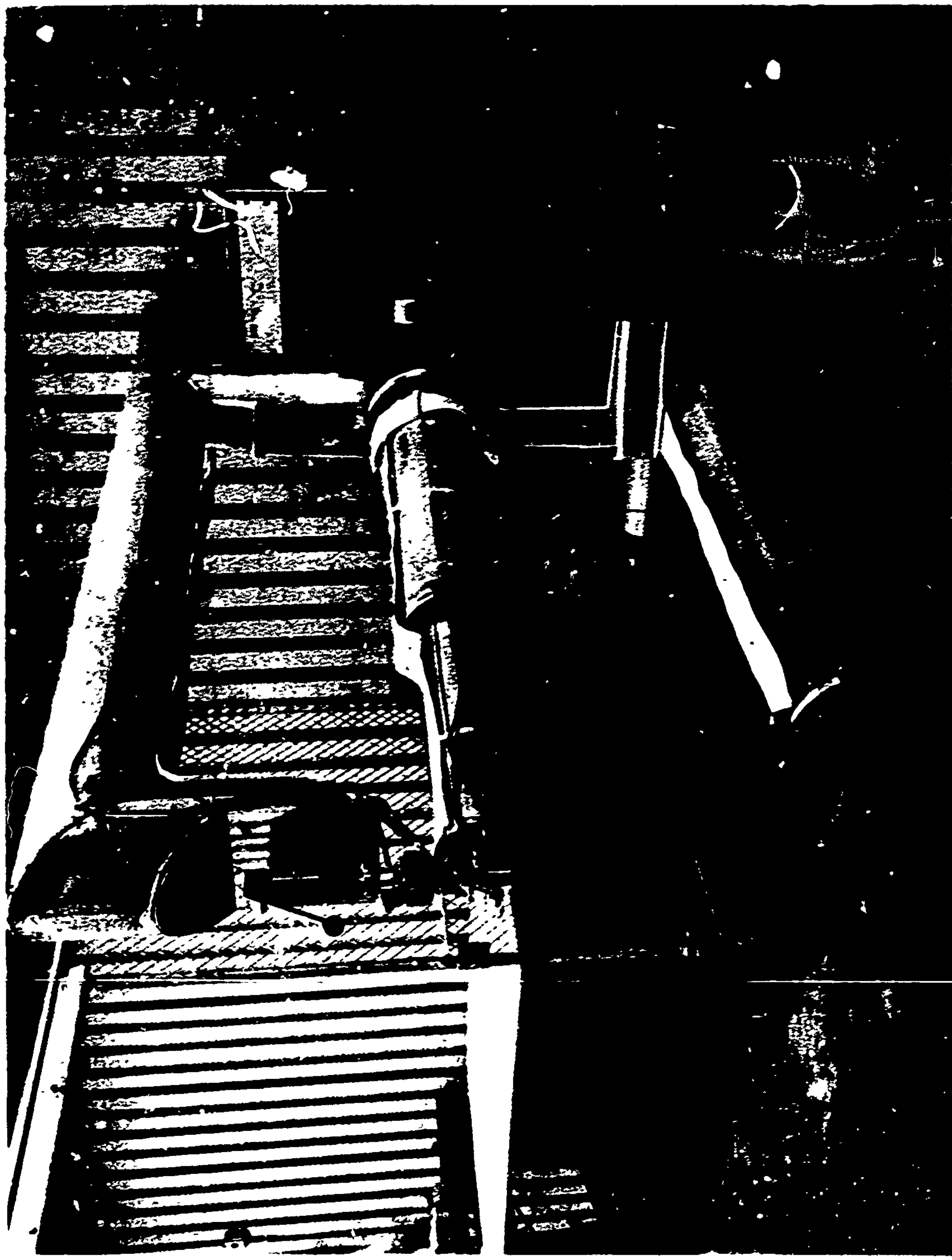

Figure 3. Welder with Horizontal Arm Installed

A transistor switching circuit is provided for each of theindividual pulse signals required, i.e., fabric advance, electrode engagement, weld pulse, electrode disengagement, second electrode engagement, second weld pulse, and second electrode disengagement. The transistors are turned on by the rotating wafer switch and, in turn, transfer the power signals to the rotary solenoids (operating the electrodes), stepper motors (operating the fabric advancement wheels), and power supply.

A close-up view of the heads, with the horizontal arm, head raising and lowering handle, head mounting splines, and bushings in place, is shown in Figure 4. This photo shows the insulation of conductor along the horizontal arm, insulation on the electrode shoes, and the use of separate flexible conductor wires to each movable shoe on the top head.

3.1.1 WELDING OF METAL FABRIC

Most of the welding in this program has been done at a speed of 3.5 inches per minute although the welder is capable of operating at more than 8 inches per minute. Higher speeds shorten electrode life and make handling of metal fabric more difficult. The operator controls the speed so that he can direct the fabric, as in the use of a sewing machine, such that the weld seam proceeds down the exact center of the overlap in the fabric layers. Since an overlap of 0.75 inches was used in most of the coupons in this program, and the centerline of the electrodes is 0.3 inches apart, only about 0.2 inch clearance between electrode and edge of overlap remains on either side. The operator must not allow the welder to run off the edge of the fabric causing the electrodes to strike together, when weld power is being supplied because this will damage the electrodes. Also, care must be taken to trim all loose yarns or other metal filaments from the edges of the fabric so that these do not short out to the electrodes. It is customary to see a tiny spark each time a weld is made, but if electrodes are misaligned, chipped, or if metal fuzz is encountered, serious arcing may occur.

If the welder is used on long seams, wherein the solenoid motors driving the wheels and energizing the electrodes are being used continuously, it is desirable to cool these motors with an electric blower or fan. If the machine is adapted for high-production use, continuous operation, heavy-duty solenoid motors would be used.

After the operator is assured that the welder heads are in proper dimensional and force adjustment, he establishes the proper power characteristics by use of the adjustments on the front of the power supply and the automatic sequencing timer.

Primary circuit voltage is indicated on the voltmeter on the power supply, and the adjacent tap switches determine the transformer taps which are being used. The upper lefthand selector has two tap steps and the righthand selector has four steps, giving a combination of eight transformer tap combinations. These tap switches not only affect the primary voltage but the "voltage adjust" rotary control on the power supply door is used to select the exact voltage desired. It has been found that this power supply should never be operated in excess of 185 primary volts. The solid state circuitry is subject to damage at higher voltages.

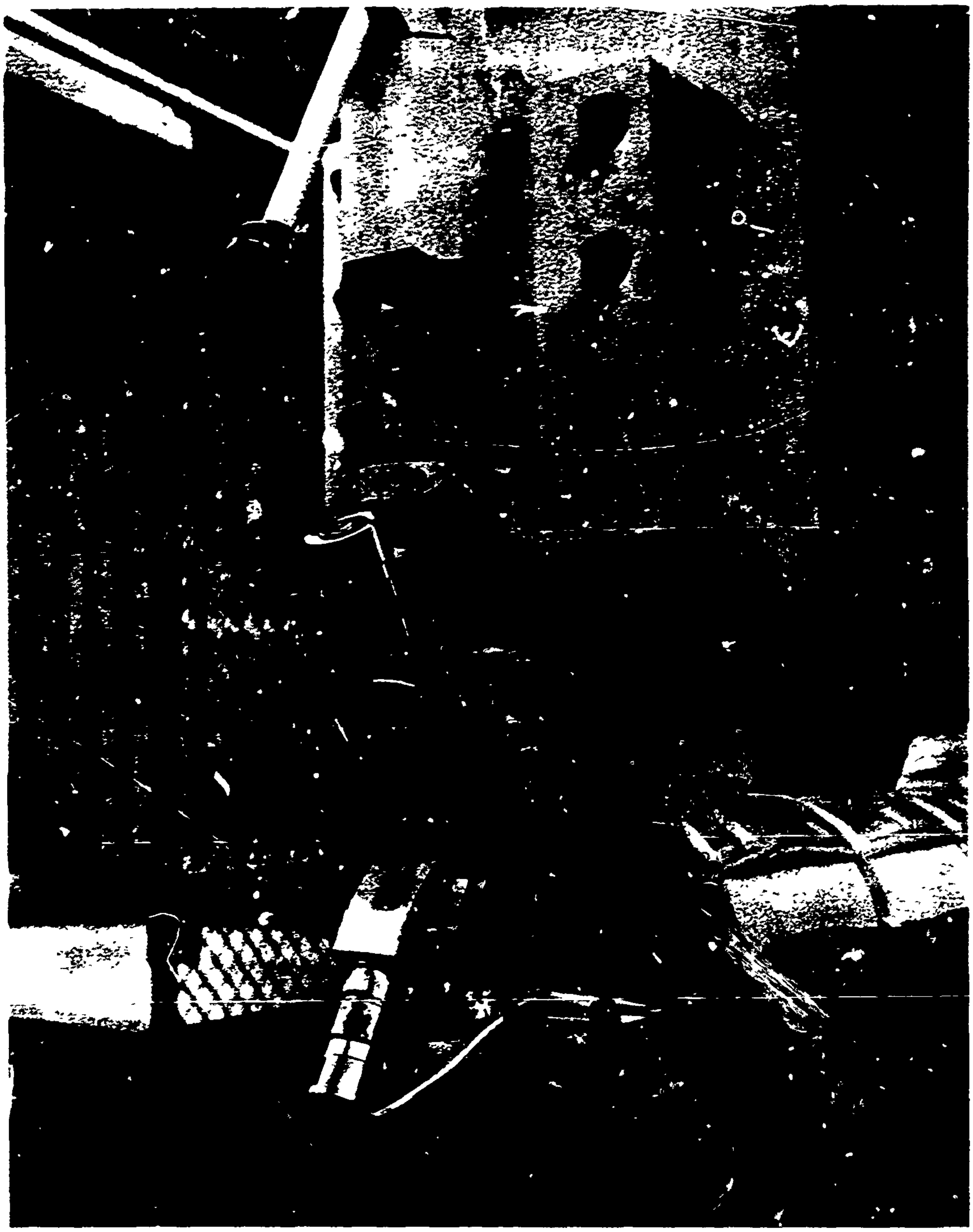

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Figure 4. Close Up View of Welding Heads

Also on the door of the power supply are a main adjustment and vernier for selecting weld pulse time from 0.1 to 10.0 milliseconds.

The Duffers current analyzer has been found ideal for measuring the short duration pulses in the secondary welding circuit. The clamp of the analyzer is placed around the flexible conductors leading from the flat plate busses to the upper electrode holders. The instrument has usually been set to read the peak amperage continuously. The reading will be a general average of peak current flowing during all pulses. The instrument may also be set to read and retain the amperage on one weld pulse. The secondary circuit voltage is of the order of two-to-eight volts so that there is little danger to the operator even though he is holding the metal fabric. Reasonable safety precautions should be taken, however, to assure that he is not grounded. It is also recommended that he wear protective eye glasses although there has never been any indication that particles are thrown out even when arcing happens to occur.

3.1.2 WELDER CERTIFICATION

Coupons used in certification of the welder were cut at least 1-1/2 inches wide and approximately 3 inches long. They were then tack welded together with three or more spots using the hand-held welder and Unitek power supply. The double-row weld was then placed across the 3/4-inch overlap of the two coupons, straddling the three tack welds. The welded coupons were then raveled under a microscope, removing yarns from either side so that test coupons with the correct number of yarns, corresponding to one-inch in width, were produced. Careful alignment of the two coupons during basting is necessary to assure uniform loading of the seam. Since most metal fabrics vary in strength between warp and fill directions, note must be made of the direction in which the coupon is being pulled so as to relate the weld strength to the proper parent fabric strength.

The coupon is inserted in the Instron tensile machine test jaws and is accurately aligned in a vertical position. Voltage, current, pulse time, head spring force, welding speed, and identification of the fabric are recorded on the certification sheet, along with the time, date, and test results, including weld efficiency.

During actual qualification testing, all coupons were statistically analyzed and none discarded. No changes were made to the welder except for occasional redressing of electrodes or replacement of electrodes if required.

3.2 WELDER REFURBISHMENT

The upper spot welding head mechanism and support structure is shown in Figure 5 and the disassembled components of the welder head are shown in Figure 6. The upper and lower welder head assemblies are identical and interchangeable.

The upper welder head (Figue 6) was disassembled and carefully inspected in detail. The fit between the welder head housing (4) and the electrode plungers (1) and (2) was surprisingly good and showed little evidence of wear. The chrome-plated channel in the aluminum housing did reveal minute,

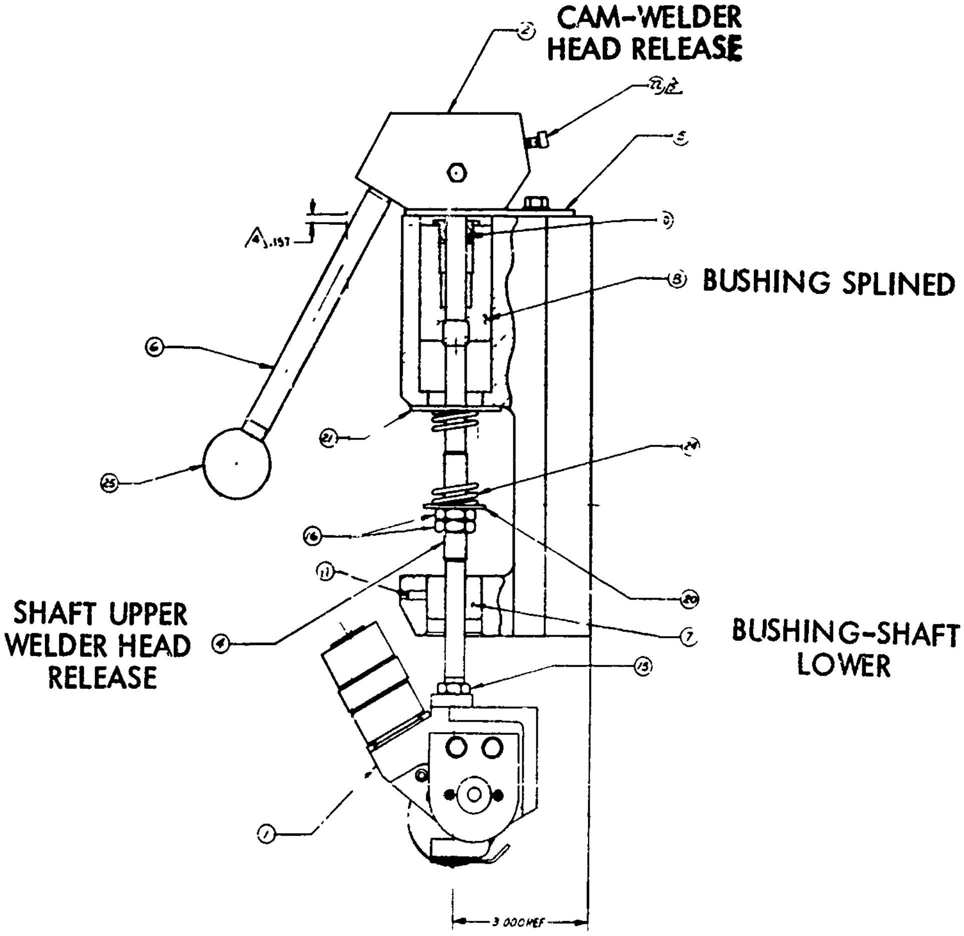


Figure 5. Support Assembly, Upper Weld Head

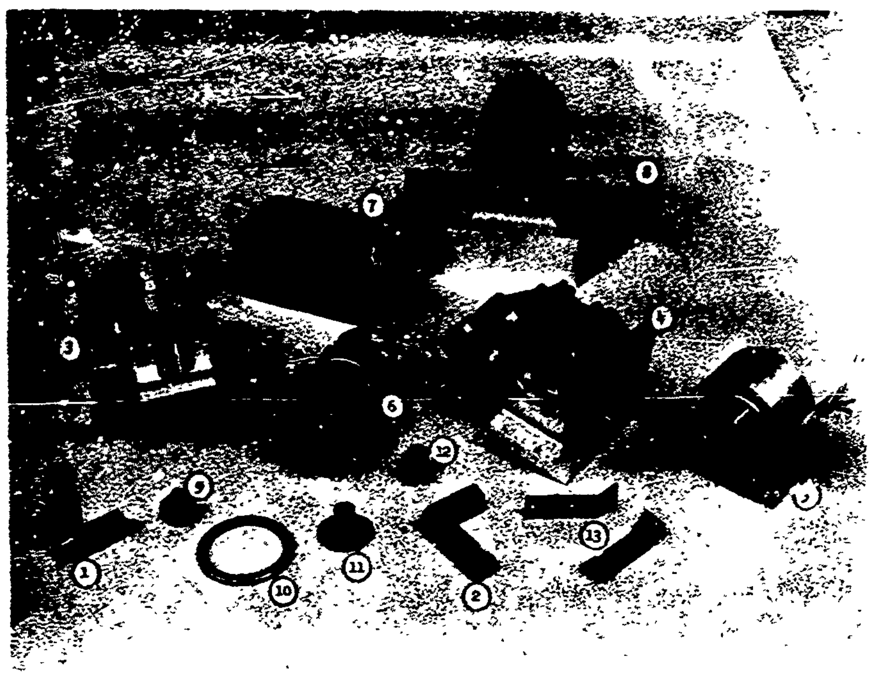


Figure 6. Welder Head Parts

1. Electrode Plunger - R.H.
2. Electrode Plunger - L.H.
3. Welder Head Housing (Upper)
4. Welder Head Housing (Lower)
5. Rotary (Cam) Solenoid
6. Stepper Motor
7. Shaft Cam
8. Lower Weld Head Support Fitting
9. Electrode Plunger Spring
10. Drive Gear
11. Drive Gear
12. Drive Gear
13. Electrode Holders

chipped, sharp edges at the ends of each channel that contributed to the chattering action. These sharp edges were honed smooth.

The electrode plungers (1) and (2) were also in good condition although there were some shallow lateral grooves in the cam slot that could have been caused by the impact of the solenoid cam. These were milled and honed smooth.

Inspection of the upper weld head support assembly (Figure 5) revealed that the case hardened splines on the bushing (8) and the shaft were loose fit and galled. The shaft was also bent. As both parts required replacement it was decided to incorporate several design improvements discussed in following sections. Briefly, a larger diameter shaft and spline was used. The bushing was redesigned and changed to a dissimilar material. A new bushing was also added at the top of the housing to react side loads from the release cam (2), thereby reducing loads and wear on the splines. The lower bushing was reworked to the increased shaft diameter. The welder head cam release was redesigned and reworked to prevent disengagement of the splines during retraction of the upper head.

New insulating inserts in the electrode plungers, as well as new electrode holders (Figure 6, Item 13) were fabricated and installed. One rotary solenoid cam was worn considerably and was replaced, but the second cam was in good condition. The electrode cover plates that support the plungers laterally were honed smooth, as required, to prevent binding when the attachment screws were snugged down.

Considering the fact that several million spot welds had been made with this machine, with only superficial maintenance required, the parts were in generally good condition.

The excessive clearance and galling in the shaft spline, permitted the welder head to rotate slightly which could produce some electrode misalignment. (The machine was designed so that the centerline of the electrodes were on the centerline of the shaft. Therefore, if all the tolerances were zero, rotation of the shaft would not cause electrode misalignment.) The excessive spline clearances and galling contributed to the erratic operation, chatter, and difficulty in maintaining electrode adjustments.

The spline wear was caused primarily by impact of mismatched splines (no self-aligning mechanism was incorporated) when the upper weld head was raised and lowered. The shaft spline and bushing spline were designed so that the splines disengaged to allow rotation of the welder head when the head was raised from the work piece, to facilitate welding of complex shapes. The majority of the time the head is raised to the up-locked position only to clear the work piece or for inspection and maintenance. When released from the raised position, the spring caused the shaft to be driven downward and frequently the splines mismatched and accumulative damage was experienced. Also, both splines were of similar case-hardened material which increased friction and galling.

Although the shaft was not intended to move during welding operations, the dynamic complexity of the structure and mechanism produced some rebound during each electrode impact. Therefore, galling and friction in the shaft splines and bearings could cause erratic tolerance control and reproducibility of welds (this problem was accentuated on the thinner fabrics investigated during this program). To correct this problem several changes were made in the upper support assembly:

a. The splines were increased in diameter and clearances reduced to a practical minimum of 0.0005 inches. A new shaft was made from heat treated, hardened steel and the female splined bushing fabricated of Oilite bearing material.

b. A new bushing was added at the top of the shaft to react side loads caused by the welder head release cam, thereby eliminating side and bending loads on the splines and shaft.

c. The shaft diameter was increased to approximately 9/16 inch to increase bending stiffness and strength.

d. The welder head release cam was redesigned and reworked to provide a two-position up-lock for the shaft, with a stop to prevent inadvertent motion to the full-up position that disengages the splines. To rotate the head, the stop can be manually removed and the shaft raised to the full-up position, which disengages the shaft splines.

Other design changes are recommended if very high production rate welding is anticipated in the future. However, these changes were beyond the scope of the current program:

a. Replace the aluminum welder housing (Figure 6, Item 3) with non-magnetic, hard stainless steel.

b. Redesign the electrode plungers to provide a "heel" for installation of a bolt and nut to support the heavy electrical power supply cables. (At present this reciprocating load is reacted by two small screws in insulating nylon inserts.) Also, hard chrome-plate the plungers.

Various types of lubricants have been investigated including some new lubricants for use in the close tolerance moving parts. Due to the extremely small clearances in the assembly, even typical dry lubricants such as Molykote appeared to be excessively thick and would eliminate existing clearances. As all bearing surfaces are now of dissimilar materials (such as Oilite against steel) it was decided to eliminate further considerations of these type of lubricants and instead a low viscosity silicone lubricant was used.

During check-out operations, after assembly of the reworked welder head, several other problems were encountered. Essentially all backlash and chatter had been eliminated but the shaft clearance was so close that the medium press fit of the bushings in the housing caused sufficient reduction in the bushing inside diameter to cause shaft friction which necessitated rework of the bushing. Also, the as-purchased solenoids were found to be only loosely controlled in external geometry which necessitated shimming to fit on installation.

While good welds were then achieved on the relatively heavy Karma fabric, arcing and burn-through occurred on the new thinner fabrics, especially at the right hand electrode. Further analysis revealed that the 48-point wafer switch in the programmer was excessively worn and required replacement. Several leaking capacitors also had to be replaced.

Visual examination of weld nuggets indicated that a large improvement in quality and consistency of nuggets had been achieved, but occasionally incomplete nuggets still occurred. Therefore, an 8-channel Sanborn recorder was used to instrument each of the plunger solenoid drive motors, the fabric speed stepper motor, and the two electrical busses, in order to record the sequence of events as signaled by the programmer. Records were taken at various weld speeds on coupons of 1/2 mil Chromel R and 1 mil Karma fabric. Analysis of the data indicated that the "fabric advance" signal to the stepper motor occurred 30 to 50 milliseconds before the signal for retraction of the right hand electrode. No overlap existed on the left hand electrode sequencing. This sequence is controlled by a 48-point wafer switch in the programmer and only 3 of the 48 contacts remained unused. As no off-the-shelf switches with a larger number of contacts could be found on the market it was decided to rewire the existing wafer switch to utilize the total capacity of the switch in an attempt to eliminate the overlap of sequences.

The rewired circuits were tested again with the Sanborn recorder and it was found that the overlap was nominally eliminated (as some tolerances existed in the timing sequence, a worst case accumulation of tolerances could however cause a small overlap). A series of 0.5 mil Chromel R 51 x 51 fabric coupons were then tensile tested with joint efficiencies (based on average parent fabric strength) of 91.9, 84.5, 81.1, 71.0, 60.7 and 65.5%. As these were all made with the same welder settings, it was not apparent why the constant degradation of weld efficiency occurred. Inspection of the welder head indicated that the machine was operating very smoothly and efficiently. Visual examination of the weld nuggets under the microscope indicated exceptionally good nugget formation. Two coupons of Karma fabric were then welded for a reference check and these tensile tested at 94.6 and 87.7% joint efficiency.

An oscilloscope was connected to the welder to permit analysis of the weld pulse characteristics. Photographs of the pulse trace on the oscilloscope were made and the resulting data are shown in Figure 7. Operation was studied with each electrode isolated, and also with both electrodes operating. It can be seen that the pulses are clean and very consistent. Rise and fall times are extremely fast and the peak power pulse is flat with very small deviations from peak voltages.

As the erratic welds and weld failures typically occurred on the right hand electrode, the system was rewired to reverse the power supply electrical pulses to the two electrodes. Subsequent tests still produced erratic welds in the right hand electrode.

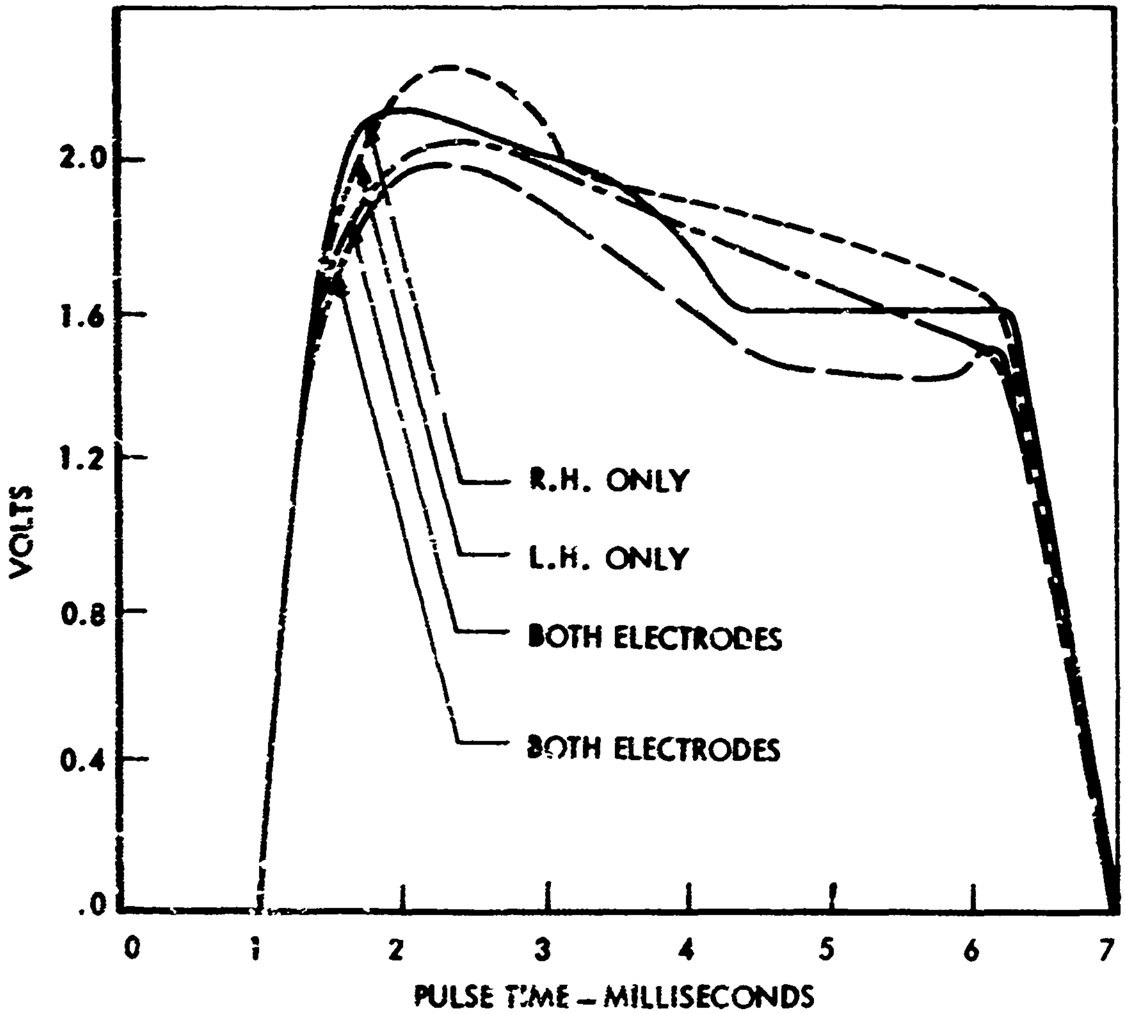


Figure 7. Weld Pulse Characteristics

As a result of these tests, attention was again redirected to the welder heads. An ohmmeter revealed an occasional shorting in the right hand electrode. The lower fabric drive wheel boss was found to be worn and the wheel sporadically contacted and shorted to the right hand electrode. A spacer was installed and this malfunction was eliminated. However, the ohmmeter still indicated occasional slight shorts. Microscopic examinations of the welder head revealed a relatively large amount of metal fabric filament fragments that were dislodged and accumulated during the welding operation. However, due to the small diameter of these filaments it is probable that these shorts burned out at very low power levels and produced little effect on the welds. Although all parts were recleaned, new welds continued to generate some filament fragments.

Concurrently with these studies, test coupons were made to sample the effect of these changes. In all, a total of 203 coupons were welded and tensile tested. This included:

a.	55 x 55 plain weave, 0.5 mil Chromel R	120 coupons
b.	39 x 39 plain weave, 0.5 mil Chromel R	8 coupons
c.	81 x 81 basket weave, 0.5 mil Chromel R	11 coupons
d.	58 x 58 basket weave, 1.0 mil Karma	64 coupons

Good welds, exceeding 85% joint efficiency were now consistently obtained on the heavier 81 x 81 Chromel R fabric and the Karma fabric. The 81 x 81 fabric consistently exceeded 92% and ranged up to 98%. More than 17 of the 55 x 55 Chromel R coupons exceeded 85% joint efficiency and ranged as high as 99%. It was very encouraging that sufficient evidence had accumulated to indicate that the welder had the potential to produce minimum joint efficiencies exceeding 90% or better on most metal fabrics.

As the right hand electrode typically produced the erratic welds the problem appeared to be associated with sliding friction in the electrode plunger due to the side loads produced by the relatively stiff and heavy power supply electrical cables attached to the heel of each plunger. A revised method of floating supports for the cables essentially eliminated that problem and joint efficiencies in test coupons then increased to over 90%, although an occasional coupon would still fail as low as 70% on the thinner, low density fabrics.

The welder now consistently functioned smoothly, with uniform electrode forces and velocities. Further efforts to improve weld efficiencies in the thinner fabrics required analysis of other welding system variables.

3.3 ANALYSIS OF WELDING VARIABLES

Experiments were conducted with three electrode diameters, and several edge radii, as well as different opposing electrode diameters. The standard electrode normally used was 0.050 inches diameter with sharp, clean edges (flat contact surfaces).

Both 0.035 and 0.065 inch diameter electrodes were experimentally evaluated. No appreciable change in performance was noted although the 0.050 electrode was slightly superior. Weld nugget diameters were not visibly

Table I

OPTIMIZED WELDING PARAMETERS

Fabric Coupon Type	Number Fabric Layers	Transformer Tap Setting	Pulse Duration ms	Head Force lbs	Voltage	Amps
39 x 39	2	1 & 2	5	11	165	585
	4	1 & 2	5	11	165	555
55 x 55	2	1 & 2	5	11	158	510
	4	1 & 2	5	11	158	450
55 x 55 to	2	1 & 2	5	11	165	575
39 x 39	4	-	-	-	-	-
81 x 81	2	1 & 2	5	11	160	505
	4	1 & 2	5	11	165	390
80 x 81 Multi-drawn	2	1 & 2	5	11	160	525
	4	1 & 2	5	11	165	440
58 x 58 Karma one mil Filaments	2	1 & 2	5	11	165	520
	4	-	-	-	-	-

prominent difference between the machines is that Reicherter was equipped with an automatic drive to produce constant head velocities of 0.05 inch per minute only, but standard loading rates used on the Instron was 0.5 inches per minute.

In order to explore the influence of the difference in the rate of load application, six welded coupons of thin 39 x 39 fabric were tested in the Instron at the standard fabric test rate of 0.5 inch per minute. Joint efficiencies ranged from 99.1% to 80.2% with only one of the six coupons failing below 86.8%.

Two additional coupons of 39 x 39 fabric welded to 39 x 39 fabric were tested on the Instron at 0.05 inch per minute to simulate the Reicherter machine loading velocities. Joint efficiencies dropped to 79.3 and 70.7%. Six welded coupons of 39 x 39 fabric welded to 55 x 55 fabric were again tested on the Reicherter. These failed at efficiencies ranging from the lowest of 86.8 to 100% with an average efficiency of 96%. It then appeared that the loading rate was not critical for the heavier fabrics but becomes increasingly more significant as fabric density in the welded joint is reduced.

In order to determine the relative efficiencies and influence of the right hand versus the left hand electrode performance four, 39 x 39 to 55 x 55 coupons were prepared with opposite electrodes welding adjacent to the 39 x 39 portion of the coupon (the lowest strength side). The coupons were tested on the Instron machine and both electrodes produced nearly perfect spot welds: 99, 100, 100, and 98% joint efficiencies.

This test data indicated the remaining problem was unique to the thin 39 x 39 fabric joined to itself.

It is to be noted that raveling these sleazy fabric coupons to obtain a test coupon, with exactly 39 yarn across the width, and with perfect asymmetry of these yarns on each side of the joint, is extremely difficult. An asymmetry of one yarn reduces the coupon parent fabric strength by 5%, as well as the apparent joint efficiency. An error in raveling the test coupon to 38 yarns, rather than 39 yarns, and an asymmetry of one yarn on each side of the welded joint will reduce either the parent fabric coupon strength, or the apparent joint efficiency, by 10%. Meticulous attention was directed to the minimization of this problem.

Analysis of the welding of the 39 x 39 to 39 x 39 plain weave fabrics indicated that there are fewer yarns per inch than there are spot welds per inch, and the spot welds are only 0.015 inch diameter and 0.040 inch on center. It was obvious that all of the yarns could not be welded, therefore two approaches were experimentally evaluated to attempt to resolve this problem

The first approach tested involved the addition of a third row of spot welds to the welded joints using the rationale that the probability was greatly increased that all of the yarns would be welded by one of the spots in one of the three rows of welds. The condition of the electrodes appeared to be critical for this fabric and even electrode pitting, visible only with a magnifying glass, apparently reduced joint efficiency by 10% or more.

The three row of welds technique was successfully developed and produced joint efficiencies averaging over 95%.

The second approach to this problem utilized the addition of a third layer of "filler fabric" added locally in the welded joint area. The rationale for this approach assumed that the "filler fabric" would provide additional metal in the spot weld nuggets which would bridge between the widely spaced fabric yarns. This method was also successfully developed and was much less sensitive than the first method to electrode cleanliness. However, the addition of the third layer should theoretically make the joint six times stiffer. Actually the joint appeared to be only approximately twice as stiff by qualitative evaluation. Joint efficiencies consistently over 95% were also produced by this method.

As noted in the Summary, the primary criteria for this exploratory development program was the developing of highly flexible, high temperature, high efficiency joints in flexible metal fabrics. Therefore, it was concluded that the three rows of spot welds in standard single lap fabric joints would be selected for the Qualification Coupon test program as this method did not adversely affect the joint efficiency.

As wrinkling of the 39 x 39 fabric produced many testing, as well as welding problems, it was finally determined that a small weight attached to the coupon greatly assisted in the uniform chucking of the coupon in the Instron jaws prior to test. The coupon grip length was also increased from 3.5 inches to 4.0 inches to provide better opportunity for redistribution of loads in the coupon during testing. These test coupons now produced average welded joint efficiencies of 95%.

3.4 METAL FABRIC CHARACTERISTICS

The 1.0 mil diameter filament Karma fabric was used for the majority of coupon tests during the check-out period after welder refurbishment, and for a baseline qualification test material, as a very large amount of data had been accumulated for this particular fabric in this and the previous contract. A photomicrograph of this fabric is shown in Figure 8.

The description of all five test fabric styles is tabulated in Table II and the tensile properties are tabulated in Table III.

All yarns and fabrics were made from filaments that were produced by wire drawing of only one continuous filament at a time, except for the "bundle-drawn" filament fabric. The latter fabric filaments were produced by a low-cost wire drawing process that produces 100 filaments simultaneously. These 100-filament bundles of 0.0005-inch-diameter wire were twisted together with 3-Z (left hand twist) turns per inch to form the yarn used to weave the 80 x 81 fabric.

Fabric Research Laboratories, Inc. also wove the bundle-drawn fabric which was produced as a 36-inch-wide, 10 yard long warp, spaced at 80 ends/inch. The quality of the fabric was fair. The properties of this fabric are compared in Table IV with those of an essentially identical fabric woven from singly drawn 0.0005 Chromel R filaments. Due to the unique characteristics of the bundle-drawn filament fabric, excerpts of the FRL®

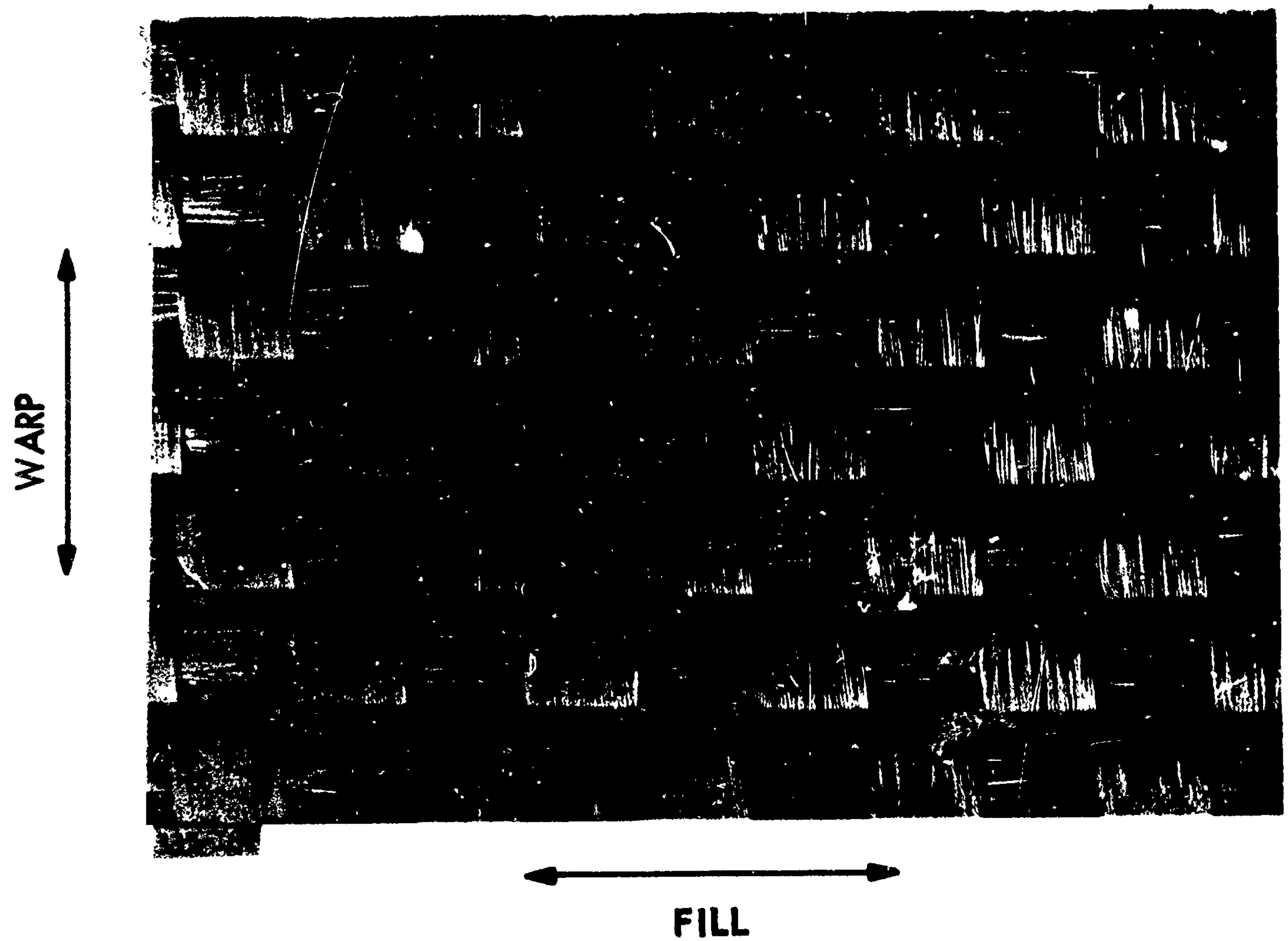


Figure 8. Photomicrograph of Multi-Filament Karma Metal Fabric (Magnified 13X)

Table II

FABRIC DESCRIPTION

Ends per Inch	Picks per Inch	Weave Pattern	Yarn Construction	Weight (oz/yd^2)	Thickness (inch)
39	39	plain	10/10/0.0005 inch, 9S/13Z-3S tpi singly-drawn	10.2	0.0065
55	55	plain	10/10/0.0005 inch, 3S/3Z tpi singly-drawn	14.4	0.007
81	81	2 x 2 basket	10/10/0.0005 inch, 3S/3Z tpi singly-drawn	19.9	0.0077
80	81	2 x 2 basket	100/0.0005 inch, 3Z tpi bundle-drawn	19.5	0.011
58	58	2 x 2 basket	7/7/0.001 inch, 2.3S /3Z tpi singly-drawn	27.4	0.012

Table III

FRL® Tensile Properties of Test Fabrics

(in warp direction)

Fabric Construction	Yield Elongation (%)	Yield Load (lbs/inch)	Modulus (lbs/inch x 10^{-3})	Rupture Elongation (%)	Rupture Load (lbs/inch)
39 x 39	- -	- -	- -	4.4	106
55 x 55	- -	- -	- -	8.6	148
81 x 81	- -	- -	- -	10.2	247
80 x 81 (bundle-drawn)	7.6	90	4.2	11.3	118.5
58 x 58 (Karma)	4.8*	278*	10.5*	12.9*	339*

*AGC Test Data

Table IV

PROPERTIES OF HOSKINS BUNDLE-DRAWN AND SINGLY-DRAWN CHROMEL R FABRIC

Yarn Designation	Weave Pattern	Ends per Inch	Picks per Inch	Thickness (inch)	Weight (oz/yd^2)	Permeability (cu ft/min/sq ft)
Hoskins Bundle-drawn Chromel R (100/0.0005 inch/ 3Z) annealed	2 x 2 basket	80	81	0.011	[illegible].5	56.0
Hoskins Singly drawn Chromel R (10/10/0.0005 inch/ 3S/3Z) annealed	2 x 2 basket	81	81	0.0077	19.9	2.1

discussion and data are included in the following paragraphs to permit a better understanding of the performance of this material:

> As Table IV shows, the two Hoskins yarn fabrics have the same weight per unit area, as would be expected since the yarns in each contain the same number of 0.0005-inch diameter filaments; the pick-and-end counts are the same; and the weave patterns are the same. The Hoskins bundle-drawn yarn fabric is thicker indicating a higher crimp ratio in that fabric; this also accounts for its higher permeability.
>
> The wrinkle recovery, flexural rigidity and folding endurance of Hoskins bundle-drawn Chromel R fabric and available data on the Hoskins single drawn fabrics are given in Table V. Both the wrinkle recovery and the folding endurance of the bundle-drawn Chromel R fabric are much lower than those of the singly drawn material indicating a greater amount of friction between filaments in the bundle-drawn yarn. For this reason the flexural rigidity of the bundle-drawn material would be expected to be higher than that of the singly drawn yarn fabric. It is in fact lower by a factor of approximately four. This may be attributed to the differences in crimp ratio between the two fabrics: the singly-drawn yarn fabric is less open indicating more yarn flattening which probably results in more friction at yarn crossovers and therefore a higher flexural rigidity.
>
> The tensile properties of raveled strips of the bundle-drawn Chromel R fabric were determined in both the warp and filling directions at 70°F on an Instron tensile tester. One-inch wide specimens gripped in leather-lined jaws were tested at a jaw speed of 0.5 inch per minute and a gauge length of 3.0 inches. The results are given in Table VI; similar data for the singly-drawn fabric is also presented.
>
> The singly-drawn yarn fabric is approximately twice as strong as the bundle-drawn fabric and exhibits a much higher modulus in both the warp and filling directions; the rupture elongation of the singly drawn fabric is approximately the same as that for the bundle-drawn fabric in the warp direction but about twice as high in the filling direction. The loss in strength is evidently a characteristic of the bundle-drawing process.
>
> Crease tests were performed in the warp direction on the bundle-drawn yarn fabric which consisted of placing a one-inch wide, folded, raveled strip under a 10-lb weight for 10 minutes, then testing it immediately in the Instron. A 2-inch by 4 3/8-inch face of the weight was in contact with one square inch of folded specimen

Table V

WRINKLE RECOVERY, FLEXURAL RIGIDITY AND FOLDING ENDURANCE OF HOSKINS BUNDLE-DRAWN CHROMEL R FABRIC

Yarn Designation	Wrinkle Recovery (%)		Flexural Rigidity ($gm\text{-}cm^2/cm$)		Folding Endurance (cycles to rupture)	
	Warp	Filling	Warp	Filling	Warp	Filling
Hoskins 80x81 Bundle-drawn Chromel R	- -	- -	- -	- -	235 255 189 278 212	281 289 300 299 264
Average	9.9	13.4	0.44	1.6	234	287
Hoskins 80x80 Singly Drawn Chromel R	33.3	30.0	1.8	5.3	968	992

Table VI

TENSILE PROPERTIES OF HOSKINS BUNDLE-DRAWN AND SINGLY DRAWN CHROMEL R FABRIC

Yarn Designation	Yield Elongation (%)		Yield Load (lbs/inch)		Modulus (lbs/in. $x10^{-3}$)		Rupture Elongation (%)		Rupture Load (lbs/inch)	
	Warp	Fill	Warp	Fill	Warp	Fill	Warp	Fill	Warp	Fill
Hoskins 80x81 Bundle-Drawn Chromel R (annealed)	7.1	1.0	93	89	3.9	13.2	9.7	3.3	111	112
	7.4	1.1	90	90	4.0	13.3	10.2	3.4	115	114
	8.4	1.0	91	89	2.9	13.2	9.7	3.3	104	112
	7.8	0.9	94	89	4.0	15.0	11.1	4.0	120	115
	7.8	0.9	89	89	4.2	14.3	10.9	3.2	115	113
	7.4	- -	89	- -	4.4	- -	10.7	- -	117	- -
	7.5	- -	89	- -	4.2	- -	10.7	- -	115	- -
	7.5	- -	89	- -	3.9	- -	11.5	- -	122	- -
Average	7.6	1.0	90	89	3.9	13.8	10.6	3.4	115	113
Hoskins 80x80 Singly Drawn Chromel R (annealed)	4.0	1.4	198	213	10.9	21.0	9.5	7.2	226	245

(Owens-Corning Fiberglas Test No. DF505). The Instron testing conditions used were the same as for the tensile tests. The results are given in Table VII. A comparison with the results of uncreased specimen tests indicates that no change in tensile properties occurs as the result of creasing. The singly drawn yarn fabric, when the comparison is based on similar testing conditions for both creased and uncreased specimens, showed a slight (approximately 3%) decrease in the rupture load as the result of creasing.

Tensile tests at 1000°F were carried out in a resistance-heated clam-shell oven. Again, one-inch wide raveled strips were tested, in the warp direction only, using the same Instron testing conditions as at 70°F except that serrated, Inconel jaws lined with two layers of the Hoskins singly-drawn yarn fabric were used to grip the specimens. The specimens were held at 1000°F for 15 minutes before testing. Specimens were also tested at 70°F with the same jaw clamping system for comparison. The results are given in Table VIII again with comparable results for the singly drawn and bundle-drawn yarn fabrics.

Approximately two and one-half square yards of each GFE fabric listed in Table II was received by the Aerojet-General Corporation. The fabric was inspected in detail and an accurate record of all material was maintained. Photographs of the two plain weave fabric yardage are shown in Figures 9, 10, 11, 12, 13, 14, and 15.

The condition of both pieces of these unique experimental fabrics was generally good, but did exhibit a few defects which included snags, loose yarns, defective selvages, and numerous sharp edge creased caused by folding and handling. Experience has indicated that typical sharp-edge creases seldom significantly affect the fabric tensile strength but they cause considerable difficulty in alignment of the tensile test coupons in the Instron jaws. The latter problem may be the predominant cause of erratic tensile strengths sometimes observed during coupon testing.

Generally, yarn snags produced little apparent reduction in coupon strength, but occasionally caused welding difficulty as the snagged yarns tended to hang-up on the welder electrodes. Except for grossly defective, or damaged, fabric specimens, tests of the best and worst sections of the fabric produced only normal test data scatter in both parent coupon and welded coupon tests.

The singly-drawn filament 81 x 81 two-by-two basket weave fabric was of very good quality except for 20 yarn knots and one pulled fill yarn.

Aerojet-General Corporation prepared parent fabric coupons of each fabric to determine what effect the welded coupon cleaning process had on fabric strength. This cleaning procedure consisted of a hot-water wash, hot Phos-It (Product of Wyandotte Chemical Co.) wash and a hot-water rinse, followed by a second hot Phos-It wash, hot-water rinse and deionized water rinse.

Table VII

TENSILE PROPERTIES OF HOSKINS BUNDLE-DRAWN CHROMEL R FABRIC AFTER CREASING

Yarn Designation	Yield Elongation (%)	Yield Load (lbs/inch)	Modulus (lbs/in. x10^{-3})	Rupture Elongation (%)	Rupture Load (lbs/inch)
Hoskins 80x81 Bundle-drawn Chromel R	7.8	89	4.0	11.4	118
	7.6	88	4.4	11.3	118
	7.4	89	3.9	10.9	117
	7.4	89	4.2	11.1	121
	7.6	89	4.3	11.2	117
Average	7.6	89	4.2	11.2	118

Table VIII

TENSILE PROPERTIES OF HOSKINS BUNDLE-DRAWN AND SINGLY DRAWN CHROMEL R FABRICS AT 1000°F

Yarn Designation	Test Temp (°F)	Yield Elongation (%)	Yield Load (lbs/inch)	Modulus (lbs/inchx10^{-3})	Rupture Elongation (%)	Rupture Load (lbs/inch)
Hoskins 80x81 Bundle-drawn Chromel R	70	7.7	92	4.0	10.2	115
		7.4	90	3.8	10.7	117
		8.8	91	3.5	12.7	117
		8.5	94	3.9	12.3	121
		8.9	92	3.3	12.6	118
		8.8	94	3.4	12.3	120
		8.6	96	3.6	12.8	122
Average		8.4	93	3.6	12.0	119
	1000	7.6	82	3.1	9.8	100
		8.6	81	2.8	10.9	96
		--	--	2.7	9.4	84
		9.0	85	2.4	11.5	102
		9.0	82	2.4	10.9	97
		--	--	2.5	9.5	84
		8.9	82	2.5	8.9	104
Average		8.6	82	2.6	10.7	95
Hoskins 80x80 Singly drawn Chromel R	70	4.2	176	8.5	9.8	204
	1000	4.2	175	6.6	7.9	201

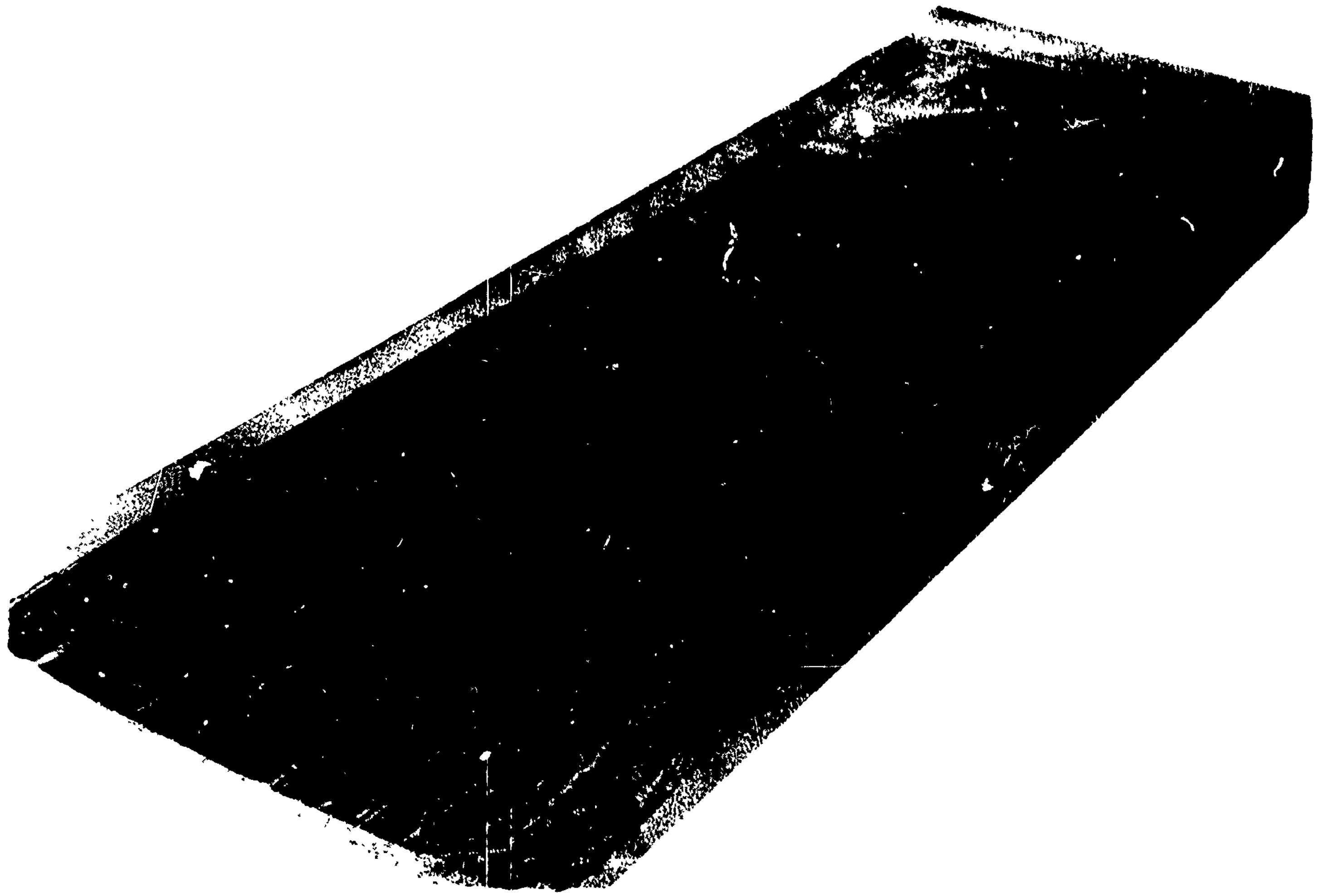


Figure 9. 39 x 39 Plain Weave Fabric

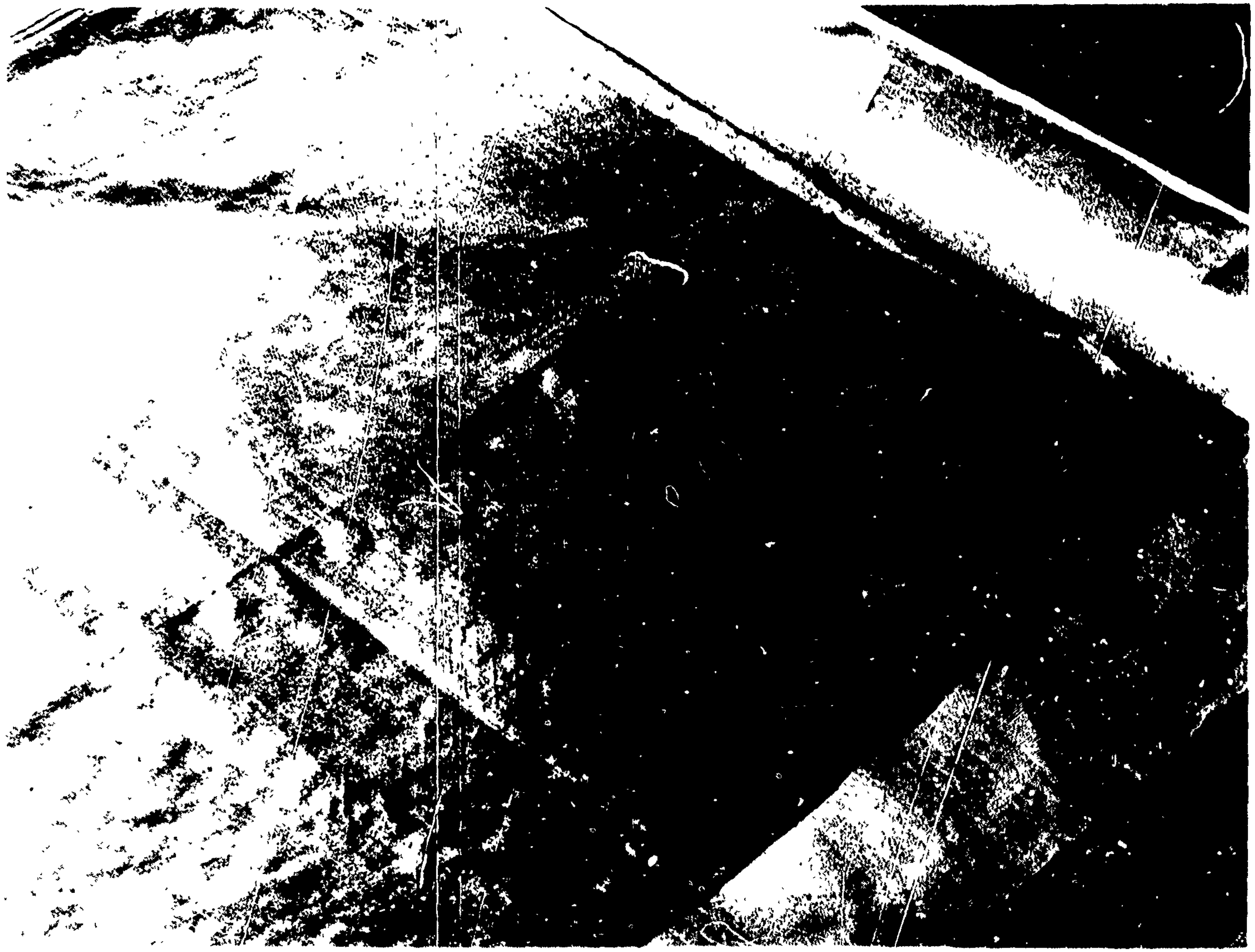
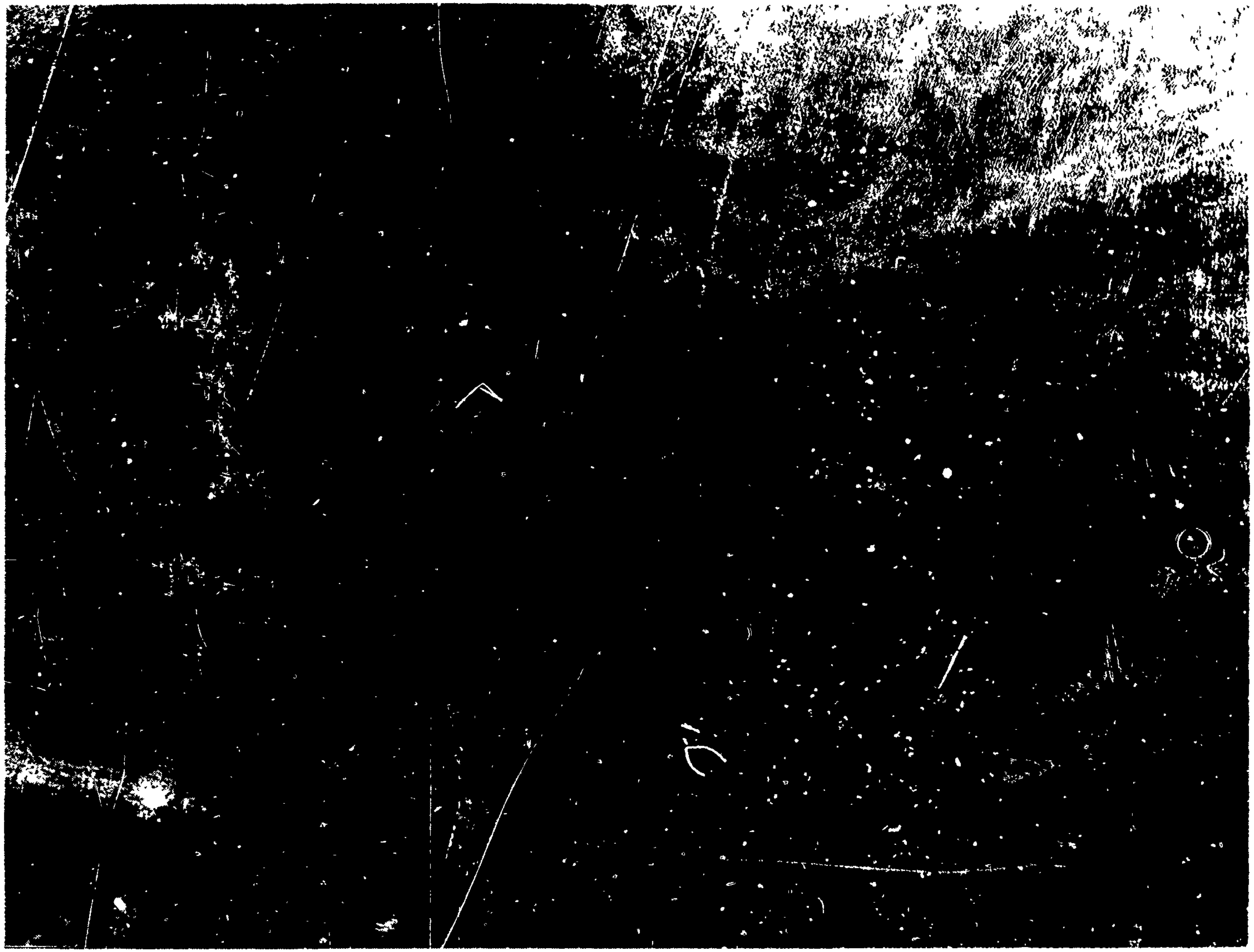


Figure 10. 39 x 39 Plain Weave Fabric Detail



1230/006

Figure 11. 39 x 39 Plain Weave Fabric Swags, Runs

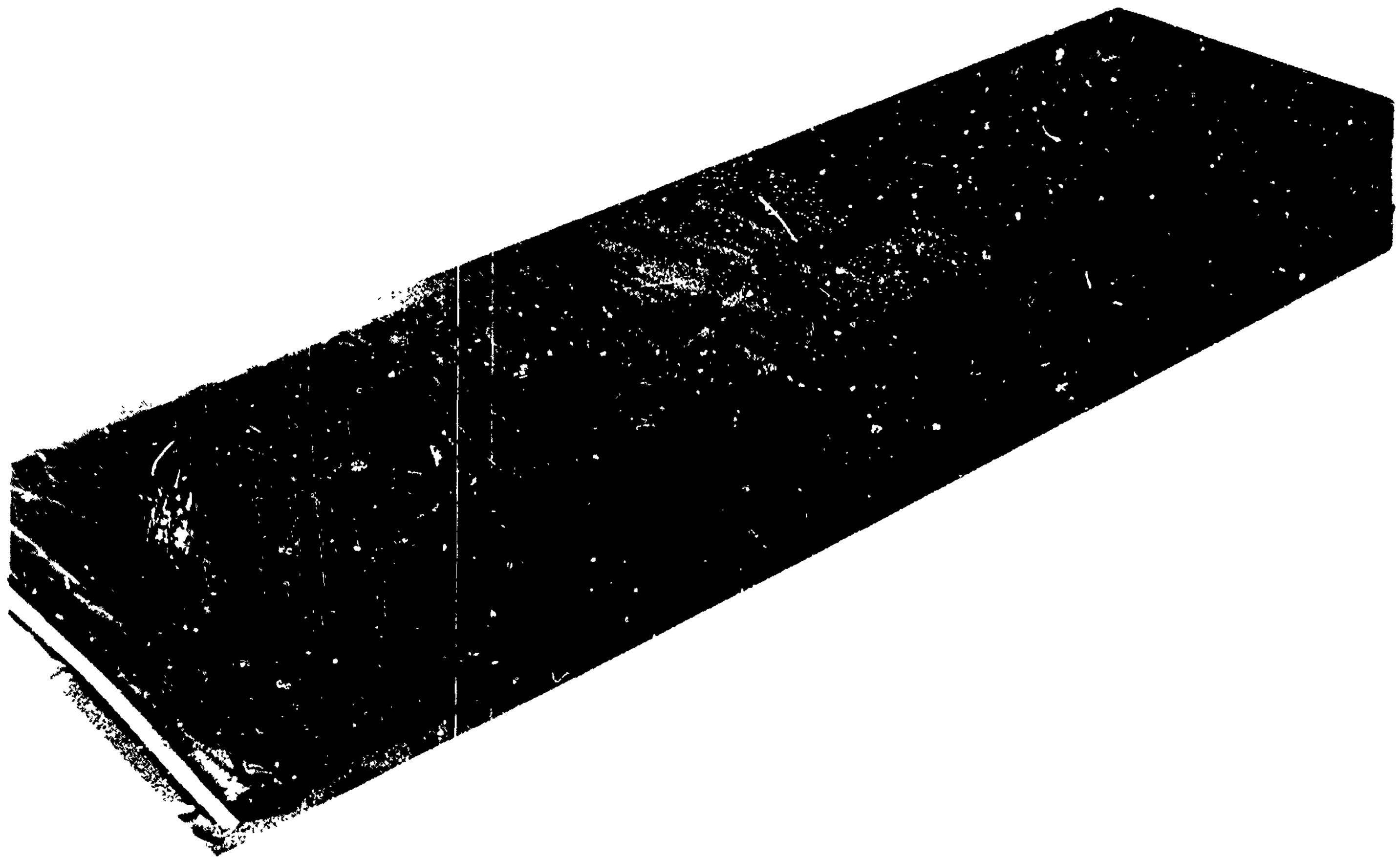


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Figure 12. 55 x 55 Plain Weave Fabric

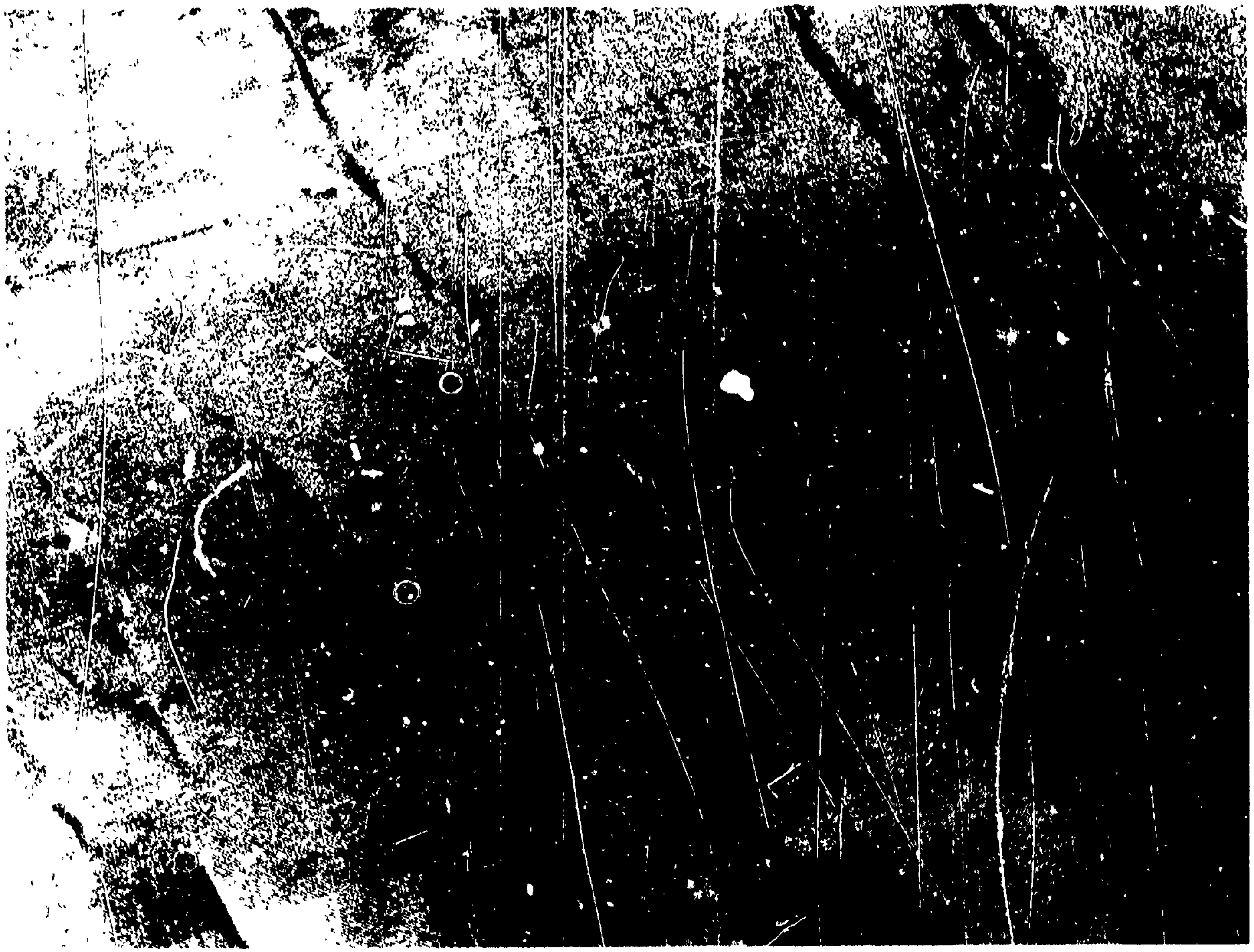


Figure 13. 55 x 55 Plain Weave Fabric

Figure 14. 55 x 55 Plain Weave Fabric

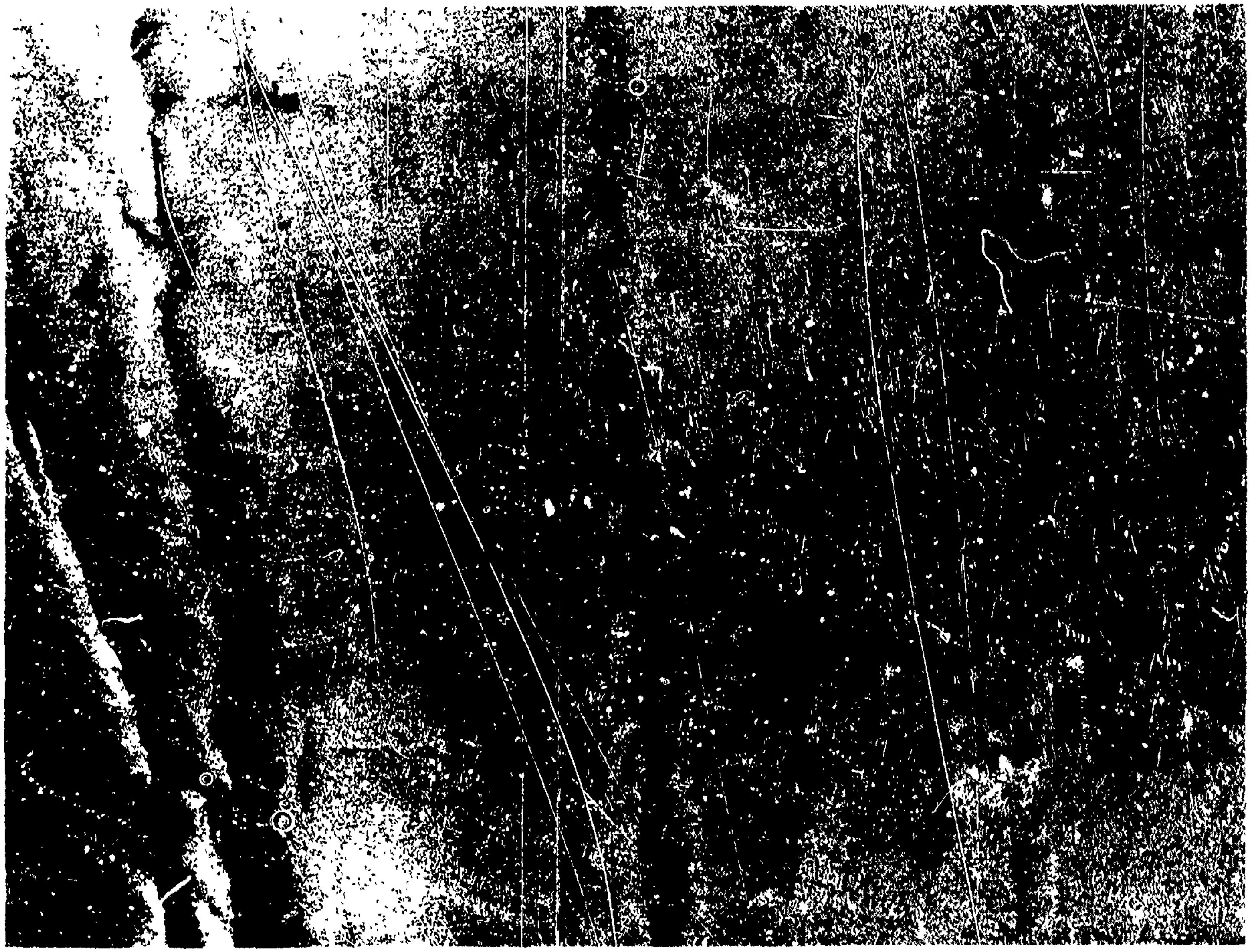


Figure 15. 55 x 55 Plain Weave Fabric

The material was then dried by rinsing in MEK or in dry warm nitrogen then immediately placed in nitrogen purged and sealed plastic bags until ready for use. Aerojet-General Corporation Phos-It cleaned the FRL® sewn coupons to remove all coatings and lubricants in order to eliminate this variable between the sewn and welded coupons. (AGC was later advised that the FRL® sewn coupons had been previously scoured with Triton X-100.)

Extensive prior testing by AGC had established that the first Phos-It washing of Karma type fabric reduced the parent fabric strength by as much as 10% due to removal of lubricants; however, subsequent washing did not further affect the fabric strength. AGC tested a small population of parent fabric coupons which had been washed in Phos-It to determine if this cleaning process, or the AGC tensile testing techniques produced test data different from those reported by FRL® for these Chromel R fabrics. The four parent fabrics were tensile tested with the results shown in Table IX.

Six coupons of the 80 x 81 bundle drawn fabric were then tested in the as-received condition (without cleaning) and produced an average rupture load of 125 p.p.i. Seven coupons of the 55 x 55 fabric were also tested in the as-received condition which averaged 158 p.p.i.

Subsequent AGC Qualification Coupon testing of welded joint coupons produced high joint efficiencies for all fabrics, except the 81 x 81 material, in excess of 96%. The 81 x 81 singly drawn fabric welded coupons consistently failed at joint efficiencies approximately 5% lower than the other fabrics. As there is no apparent reason why equally good welded joint efficiencies cannot be produced in the 81 x 81 fabric, it is possible that the average parent fabric strength used to calculate joint efficiencies (247 p.p.i.) represented an abnormal population of coupons, and that the average strength determined by AGC tests as reported in Table IX is more representative of this material.

3.5 QUALIFICATION TEST CONDITIONS AND PROCEDURES

3.5.1 AEROJET-GENERAL TEST PROCEDURES

Five Qualification Test Coupons of each welded joint fabric style or fabric combination, for each test condition, were prepared without varying the optimum weld parameters established during the exploratory development phase of the program. One "control" coupon was prepared concurrently for each group of specimens, and tensile tested at room temperature to verify that no procedural abnormalities had occurred.

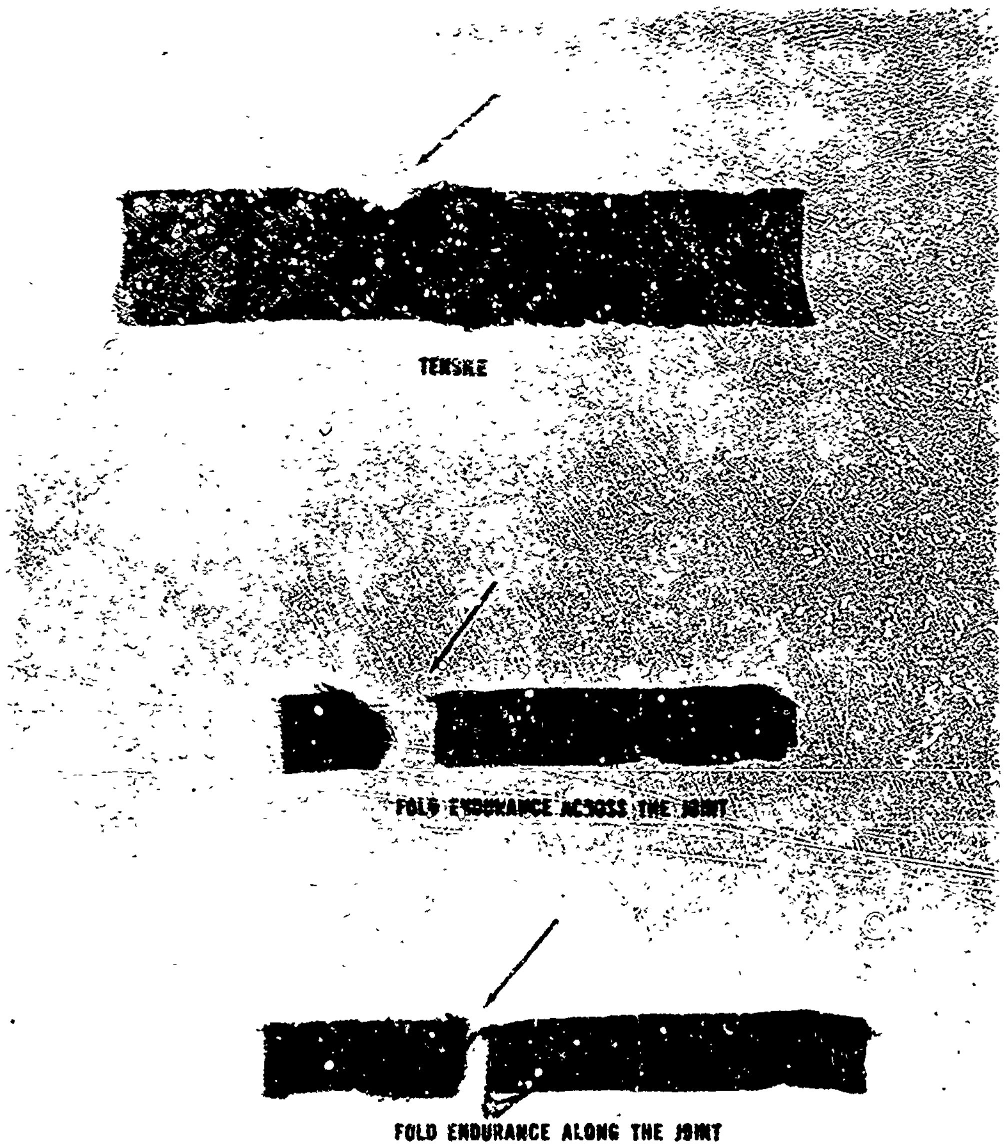
The standard tensile test spot-welded coupons were raveled to one-inch wide specimens up to the spot welded, 3/4 inch wide, overlap joint in the fabric. The fabric joint was then trimmed to within one or two yarns of the raveled fabric width. The overall welded coupon length was 6.5 inches which was chucked up to a test gauge length of 4.0 inches. Room temperature tensile tests were run in the Instron at a 0.5 inch per minute loading rate with the coupons clamped in leather-lined Instron jaws. Load-elongation curves for each coupon were recorded. Typical spot welded coupons are shown in Figures 16 through 20. An arrow in each photograph indicates the point of coupon failure.

[illegible] coupons of bundle-drawn fabric were prepared by FRL. [illegible] were of the LSc-type construction as shown in Figure 21

Table IX

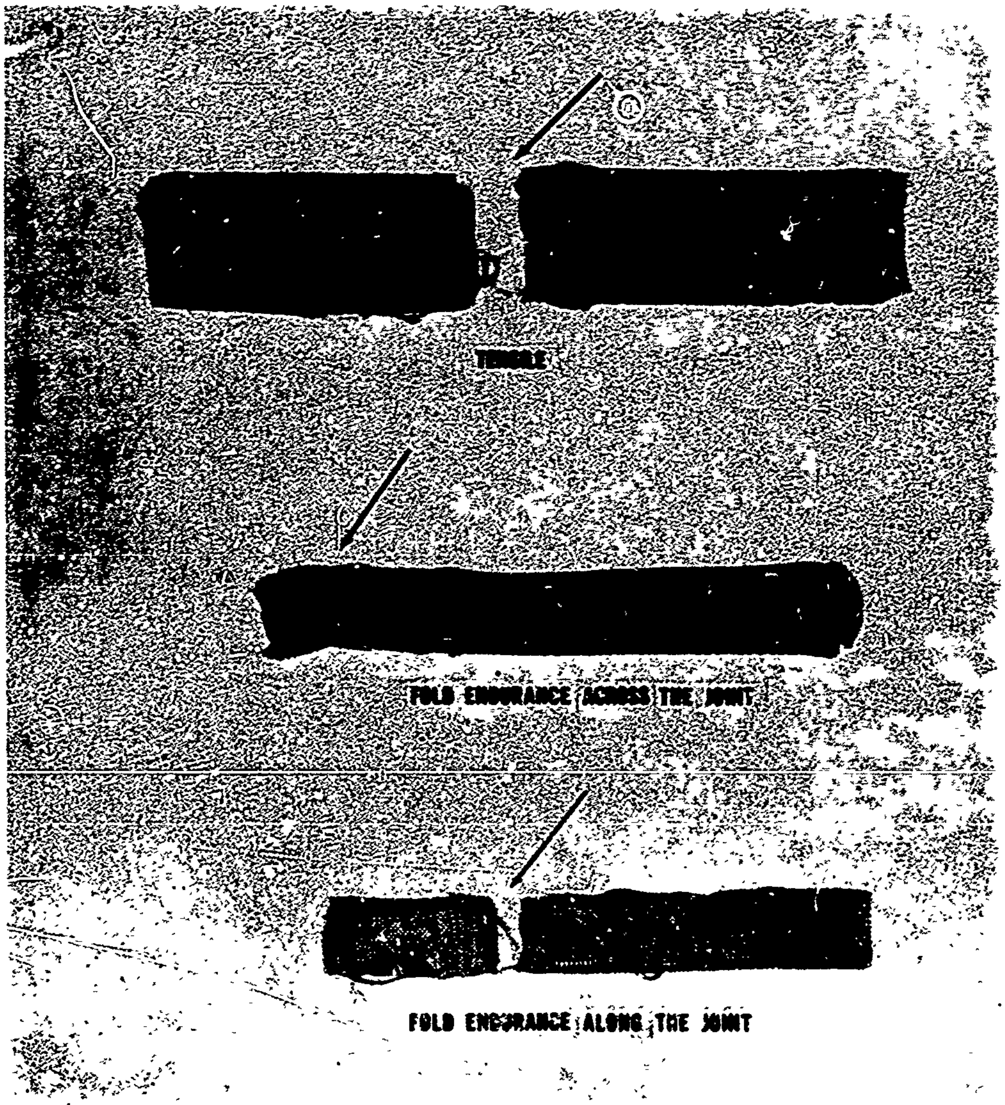
PARENT FABRIC STRENGTHS

Fabric Style	Rupture Load (lbs/in.)	
	FRL[b] Data	AGC Data
39 x 39 singly drawn		105 114 112 104 109
Average	106	109
55 x 55 singly drawn		150 15[illegible] 147 147 147
Average	148	150
81 x 81 singly drawn		228 238 227 242 238
Average	247	235
80 x 81 bundle drawn		120 123 119 114 121
Average	118.5	119



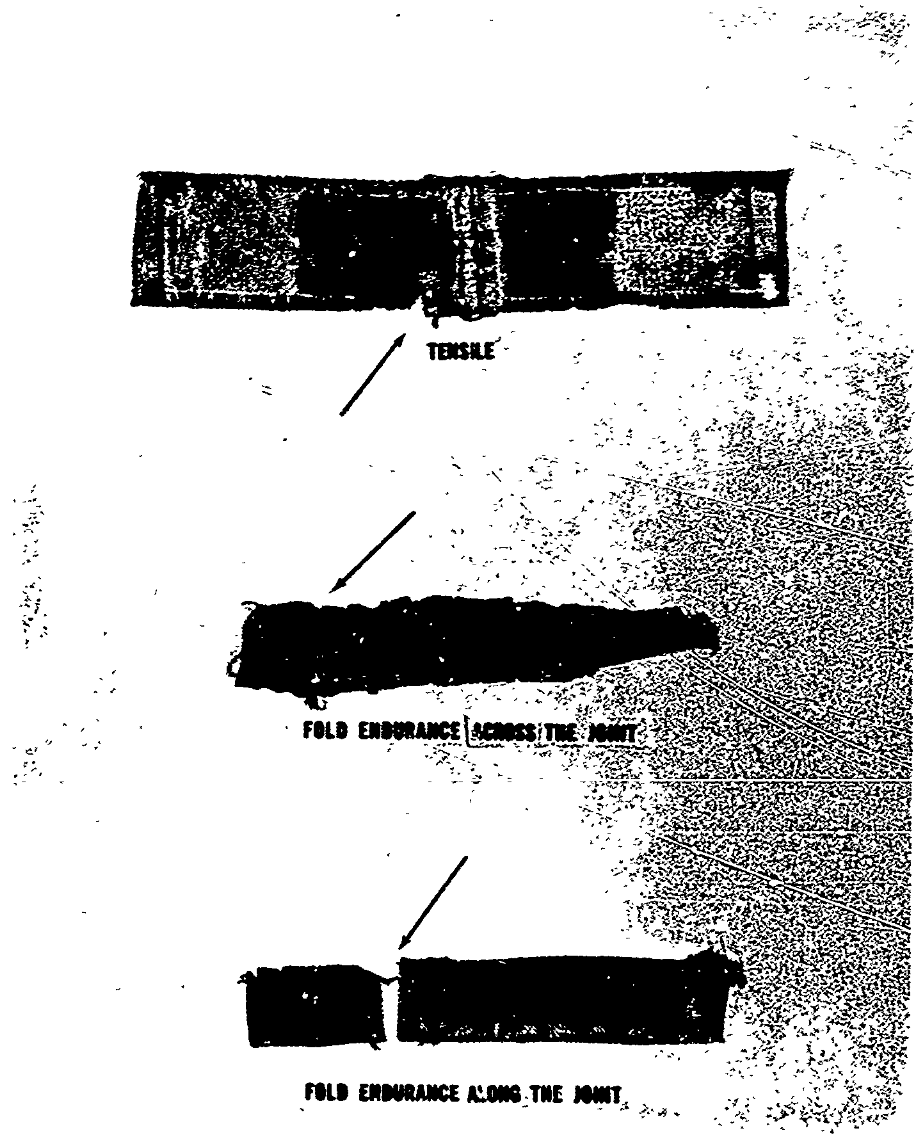
1240/028

Figure 16. Spot Welded Test Coupons 80 x 81 Multi-Drawn Filament Fabric



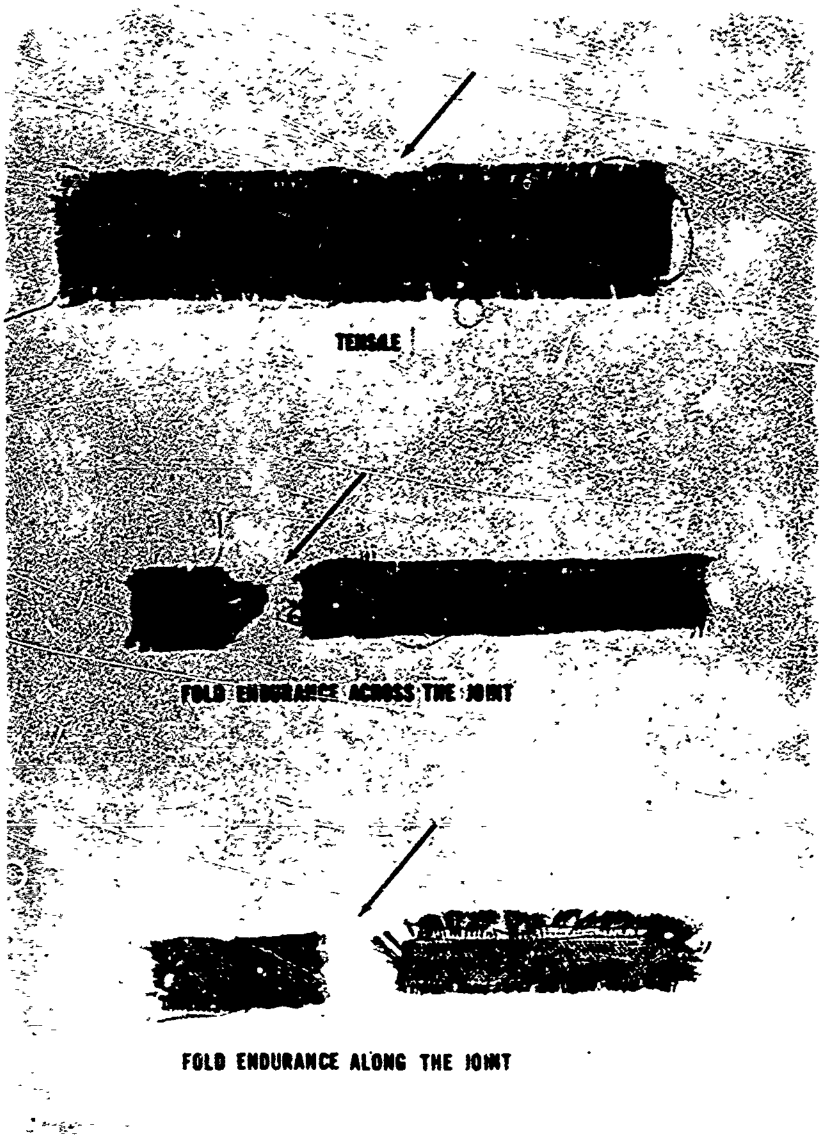
1230/024

Figure 17. Spot Welded Test Coupons 81 x 81 Single-Drawn Filament Fabric



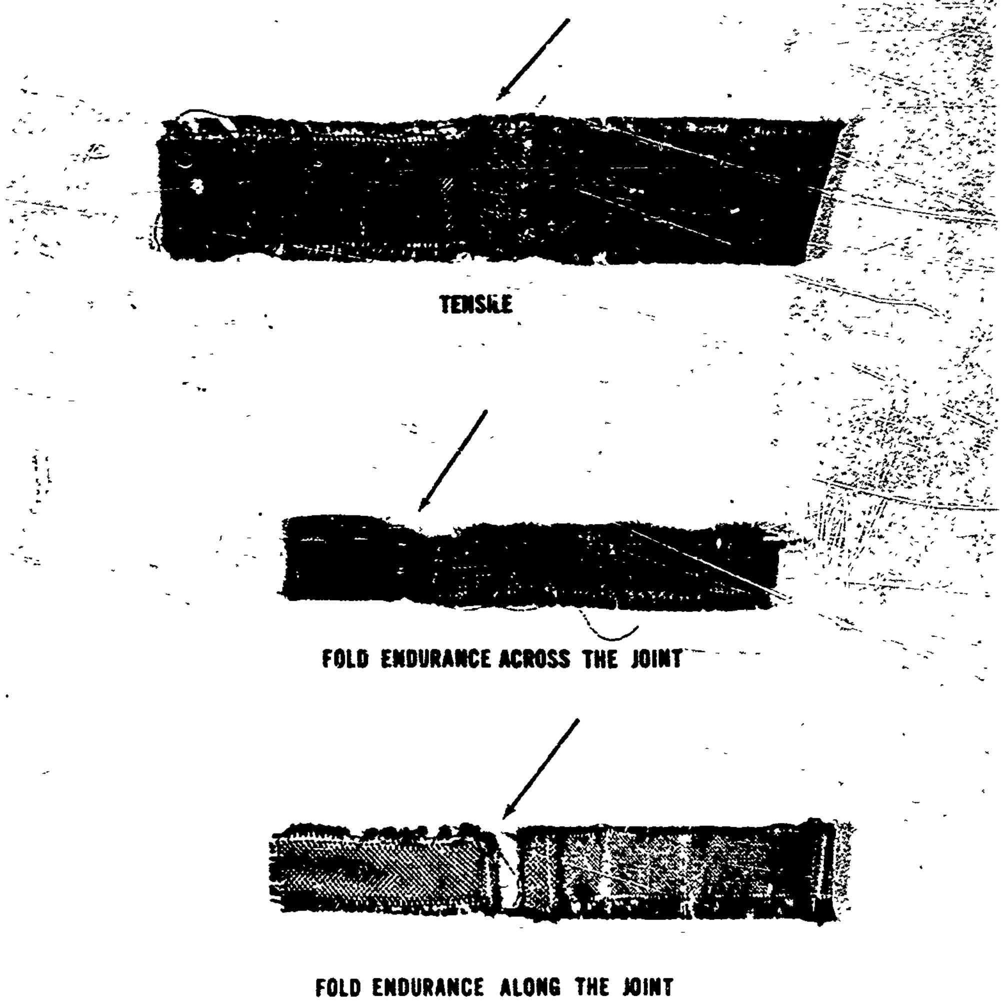
1230/C29

Figure 18. Spot Welded Test Coupons 55 x 55 Singly-Drawn Filament Fabric



1230/025

Figure 19. Spot Welded Test Coupons 39 x 39 Singly-Drawn Filament Fabric



1230/027

Figure 20. Spot Welded Test Coupons 39 x 39 to 55 x 55 Single-Drawn Filament Fabric

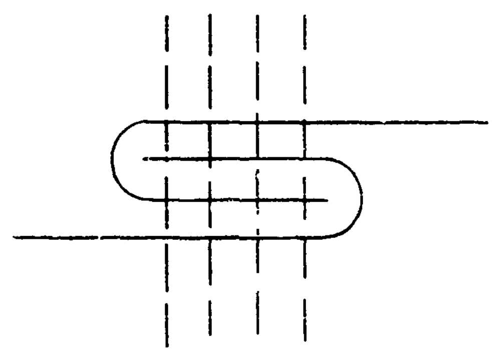


Figure 21. LSc-Type Seam Construction

consisting of four rows of stitching, approximately 60 stitches per inch, and spaced at 1/4 inch between rows. The sewing thread was the same as the fabric yarns: 100/0.0005 inch/3Z tpi and DVA coated. Photographs of the sewn joint coupons are shown in Figure 22.

The sewn joint coupon material for AGC testing was also raveled to a one inch width but the sewn joint was trimmed to within only 0.6 inch of the coupon centerline to minimize the possibility of unraveling of the stitching.

The fold endurance spot welded coupons for folding along the seam were prepared with a 0.5 inch tail on one end of the coupon and a 4-inch tail on the opposite end. The fold endurance, spot welded, coupons for folding across the seam were 4.5 inches long, measured along the seam, and 1 inch wide with the lap joint on the centerline of the -inch width. The spot welds extended from one end of the coupon for 1.0 inch along the coupon length. These fold endurance coupons were raveled and tested by FRL®.

All tensile testing was done in the warp direction unless otherwise specified.

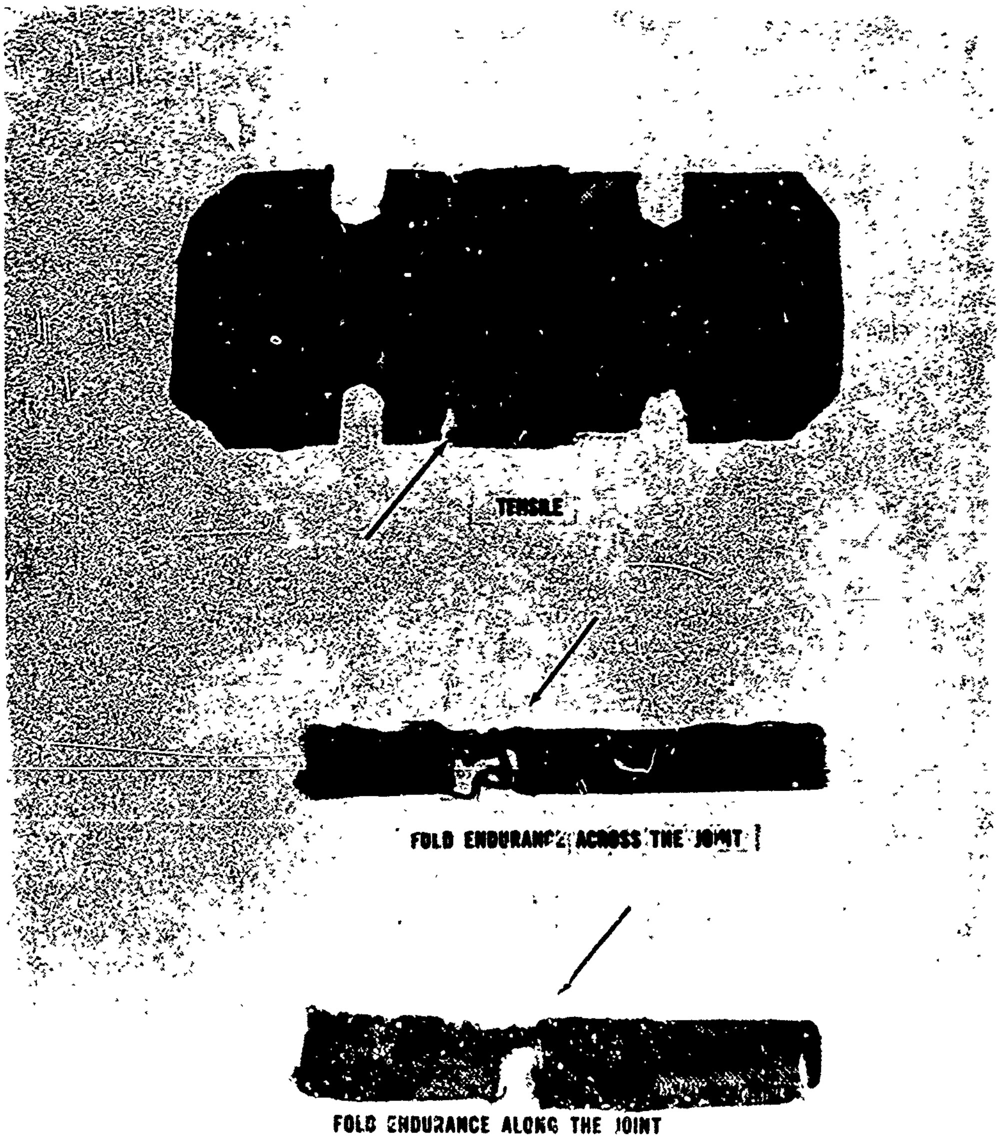
3.5.2 FABRIC RESEARCH LABORATORIES, INC. TEST PROCEDURES

All FRL® fabricated test coupons were scoured in a solution of Triton X-100 and warm water, then rinsed thoroughly before test. The tensile rupture properties of one inch wide, raveled, welded joint specimens were determined at both ambient and elevated temperature in an Instron tensile testing machine. A gauge length of 3 inches and a jaw speed of 0.5 inch per minute was used. For the 1000°F tests, the Instron leather jaw lining was replaced with two layers of the 81 x 81, singly drawn yarn, 2 x 2 basket weave fabric. The elevated temperature tests were conducted in the resistance-heated clam shell oven shown in Figure 23. Prior to testing, the samples were held at $1000^{\circ} \pm 10^{\circ}$ for 15 minutes, in addition to approximately two minutes for oven temperature recovery after insertion of the specimen.

The FRL® sewn tensile coupons, that were also tested by FRL®, were prepared as 2.5 inch wide slit seam specimens as shown in Figure 24 rather than 1.0 inch wide raveled coupons in order to eliminate the possibility of unraveling of the stitches. Slits were cut inward one-half inch from each side of the coupon, above and below the seam. The test gauge length was also reduced to 1.5 inches in order to prevent tearing at the slits.

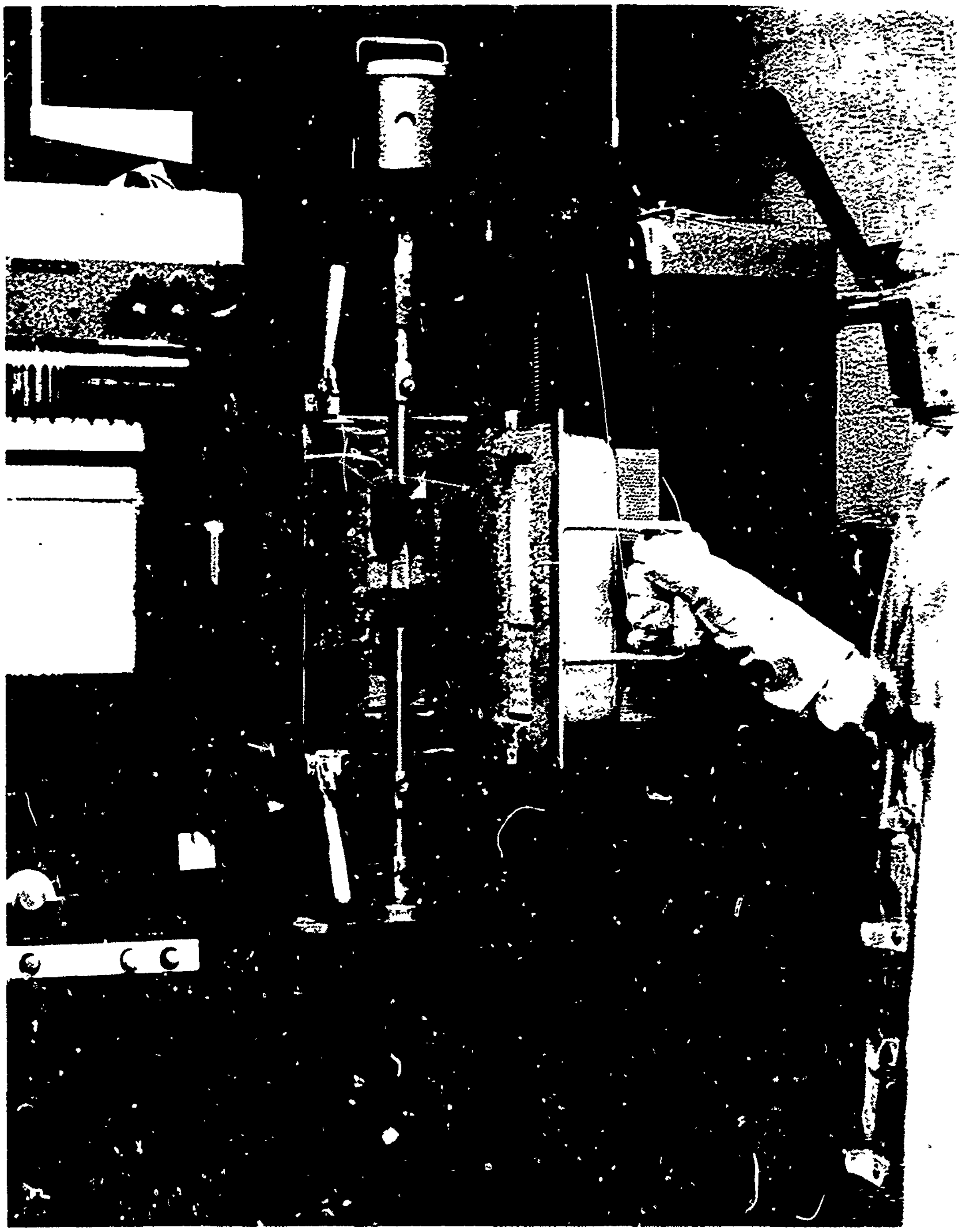
The creased joint coupons were creased in accordance with Owens-Corning Fiberglas Test procedure No. DF-505. The coupons were folded along a line of spot welds so that there were no intervening layers of fabric. These folded strips were inserted under a 10 pound weight for 10 minutes, then tensile tested immediately. A 2 inch by 4-3/8 inch face of the weight was in contact with one square inch of the folded specimen.

The MIT folding endurance of seamed coupons was determined according to ASTM method D2176-63T as shown in Figure 25. Both ends of the 0.59 inch wide coupon are clamped in jaws. The lower jaw is rotated in an oscillating movement such that the fabric is folded through an angle of 135 degrees, to either side of the center line, 180 times per minute. The surfaces



1230/026

Figure 22. Sewn Joint Test Coupon 80 x 81 Multi-Drawn Filament Fabric



1230/016

Figure 23. Clam Shell Oven

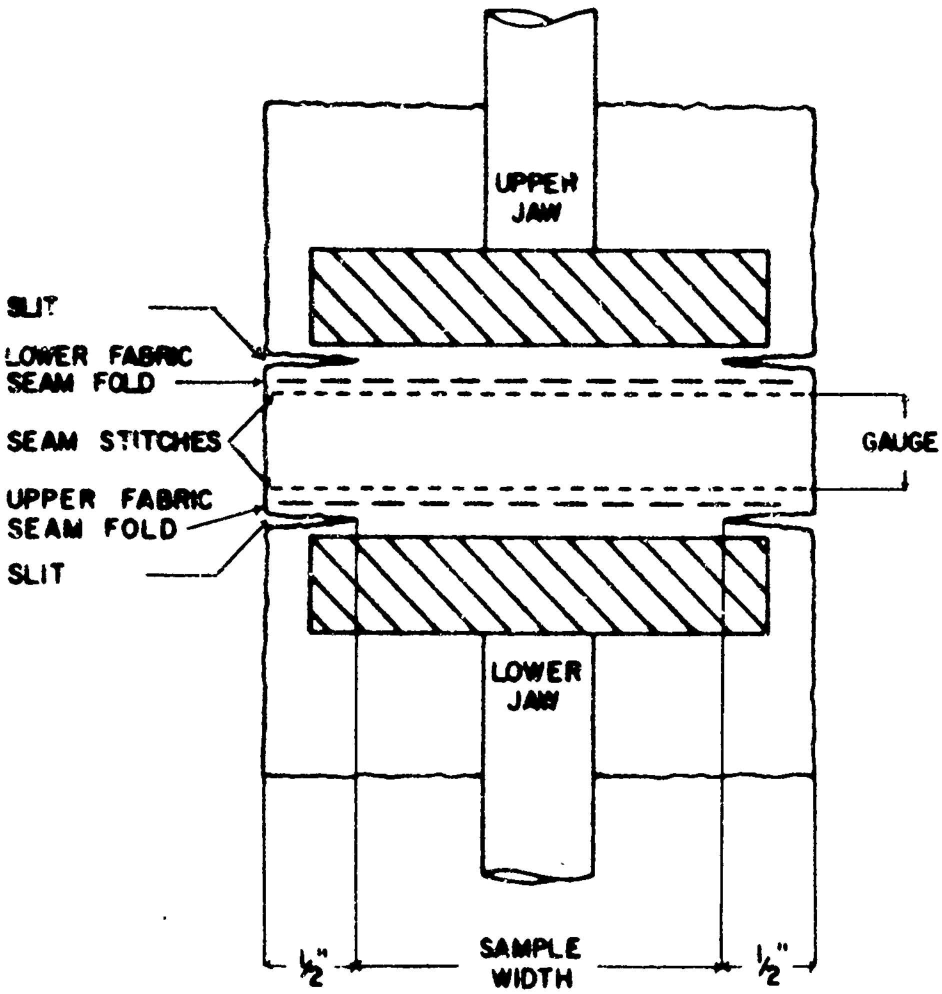


Figure 24. Slit Seam Specimen for Sewn Seams

1230/017

Figure 25. MIT Folding Endurance Tester

of the jaw edges over which the specimen is folded have a radius of curvature of 0.015 inches. A spring tension of 1.5 kg is applied to the upper jaw.

Joint test coupons were folded both along and across the lines of seaming. Those specimens folded along a line of seaming, directly at the seam, were tensioned in the warp direction; those folded across the seam were tensioned in the filling direction. The welded specimens folded across the joint were so constructed that it was possible to mount them by tensioning only one layer of fabric; however, for the sewn seam specimens the entire seam was clamped in both the upper and lower jaws so that all four layers in the fabric were tensioned. In the case of the 39 x 39 fabric welded to the 55 x 55 fabric, the 39 x 39 fabric was tensioned.

The jaw opening used was 0.02 inch for the welded coupons and 0.05 inch for the sewn coupons.

3.6 QUALIFICATION COUPON TEST DATA

The Aerojet-General Qualification Coupon tensile test data for room temperature properties is shown in Table X. The spot welded fabric joint coupons were prepared by Aerojet-General Corporation and the sewn fabric joint coupons were prepared by Fabric Research Laboratories, Inc. The joint efficiencies are calculated based on average parent fabric strengths, as is customary in the textile industry.

Tensile testing of spot welded coupons of four layers of each fabric were also conducted to establish the room temperature properties of intersecting seams. The results of these tests are shown in Table XI.

The subcontractor's Qualification Coupon test data is tabulated in Tables XII through XVII. With the exception of the 80 x 81 bundle-drawn fabric, no parent fabric strengths at 1000°F were available; therefore, the joint efficiencies for all other fabric coupons tested at 1000°F are calculated relative to the parent fabric at room temperature. (The bundle-drawn coupon joint efficiencies are calculated relative to the parent fabric 1000°F strength.)

3.7 ANALYSIS OF TEST DATA

Good agreement is shown between the AGC and FRL® room temperature tensile test data for uncreased coupons The maximum spread of test data in joint efficiencies is 4%, and the difference of the total of all average joint efficiencies is less than 0.1%. For all 50, standard, welded fabric coupons tested the average joint efficiency exceeded 96%. For all 20, four layer, welded fabric coupons the average joint efficiency also exceeded 96%. The 81 x 81 fabric consistently produced the lowest joint efficiencies, which indicates that the average parent fabric strength used may have been abnormally high, or the weld parameters may not have been optimized for this fabric.

The room temperature tensile strength of the 10 sewn coupons tested under this contract, on the 80 x 81 bundle-drawn fabric only, produced an average joint efficiency of 88%. However, the sewn joint efficiencies reported by FRL® for the other fabrics, tested under other contracts, were comparable to the welded joint efficiencies.

Table X

AGC QUALIFICATION COUPON TEST DATA FOR TENSILE PROPERTIES OF SPOT WELDED AND SEWN SEAM COUPONS AT ROOM TEMPERATURE

Fabric Coupon Type	Parent Fabric		Spot Welded Coupons			Sewn Coupons		
	Rupture Elongation (%)	Rupture Load (lbs/in.)	Rupture Elongation (%)	Rupture Load (lbs/in.)	Joint Efficiencies (%)	Rupture Elongation (%)	Rupture Load (lbs/in.)	Joint Efficiencies (%) *
39 x 39 to 39 x 39	4.4	106	3.0	99	93	--	--	--
	--	--	3.1	105	99	--	--	--
	--	--	3.5	108	102	--	--	--
	--	--	3.0	95	90	--	--	--
	--	--	3.4	102	96	--	--	--
	Averages		3.2	102	96	--	--	97
55 x 55 to 55 x 55	8.6	148	6.1	136	92	--	--	--
	--	--	6.2	145	98	--	--	--
	--	--	6.2	150	101	--	--	--
	--	--	7.3	156	105	--	--	--
	--	--	6.6	154	104	--	--	--
	Averages		6.5	148	100	--	--	91
55 x 55 to 39 x 39	4.4	106	4.7	97	92	--	--	--
	--	--	5.0	105	99	--	--	--
	--	--	5.4	109	103	--	--	--
	--	--	5.2	109	103	--	--	--
	--	--	5.0	112	106	--	--	--
	Averages		5.1	106	100	--	--	99

*Reported by FRL[8]

Table X ---Continued

AGC QUALIFICATION COUPON TEST DATA FOR TENSILE PROPERTIES OF SPOT WELDED AND SEWN SEAM COUPONS AT ROOM TEMPERATURE

Fabric Coupon Type	Parent Fabric		Spot Welded Coupons			Sewn Coupons		
	Rupture Elongation (%)	Rupture Load (lbs/in.)	Rupture Elongation (%)	Rupture Load (lbs/in.)	Joint Efficiencies (%)	Rupture Elongation (%)	Rupture Load (lbs/in.)	Joint Efficiencies (%) *
81 x 81 to 81 x 81	10.2	247	9.4	246	100	- -	- -	- -
	- -	- -	6.9	232	94	- -	- -	- -
	- -	- -	4.2	205	83	- -	- -	- -
	- -	- -	4.2	209	85	- -	- -	- -
	- -	- -	6.6	229	93	- -	- -	- -
	Averages		6.3	222	91	- -	- -	92
80 x 81 to 80 x 81 (bundle-drawn)	11.3	118.5	10.0	120	101	11.0	114	96
	- -	- -	10.8	118	100	7.5	90	76
	- -	- -	10.5	112	94	11.0	117	99
	- -	- -	9.5	111	94	10.0	105	89
	- -	- -	10.5	118	100	10.0	89	75
	Averages		10.3	116	98	10.0	103	87

*Reported by FRL®

Table XI

AGC QUALIFICATION COUPON TEST DATA
FOR
TENSILE PROPERTIES OF FOUR LAYER SPOT WELDED COUPONS

Fabric Type	Rupture Elongation (%)	Rupture Load (lbs/in.)	Joint Efficiencies (%)
39 x 39	3.0	104	98
	3.8	104	98
	3.0	101	95
	3.3	108	102
	3.8	108	102
Averages	3.4	105	99
55 x 55	6.8	141	96
	6.5	138	93
	6.3	130	88
	6.3	148	100
	6.3	150	100
Averages	6.4	141	95
81 x 81	5.5	223	90
	7.5	229	93
	4.5	217	88
	8.0	238	96
	7.5	237	96
Averages	6.6	229	93
80 x 81 (bundle-drawn)	9.3	120	101
	9.3	118	100
	10.0	112	94
	8.8	109	93
	9.3	116	98
Averages	9.3	115	98

Table XII
TENSILE PROPERTIES OF WELDED JOINTS AT AMBIENT AND ELEVATED TEMPERATURES

Fabric Description	Temp (^{o}F)	Parent Fabric		Welded Joint Coupons			Sewn Joint Coupons
		Rupture Elong (%)	Rupture Load (lbs/in.)	Rupture Elong (%)	Rupture Load (lbs/in.)	Joint Efficiency* (%)	Joint Efficiency* (%)
39 x 39 Plain weave singly-drawn yarn	70	--	--	3.6	94	89	--
	--	--	--	3.6	86	81	--
	--	--	--	3.9	106	100	--
	--	--	--	3.5	98	92	--
	--	--	--	4.1	100	94	
Average		4.4	106	3.7	97	92	97
	1000	--	--	4.1	86	81	--
	--	--	--	3.4	83	78	--
	--	--	--	4.1	94	89	--
	--	--	--	3.6	98	92	--
	--	--	--	3.4	72	68	--
Average	--	--	--	3.7	87	82	89
55 x 55 Plain weave singly-drawn yarn	70	--	--	7.5	139	94	--
	--	--	--	7.0	149	101	--
	--	--	--	7.0	155	105	--
	--	--	--	7.5	140	95	--
	--	--	--	7.8	146	99	--
Average	--	8.6	148	7.4	146	99	91
	1000	--	--	7.3	133	90	--
	--	--	--	6.9	137	93	--
	--	--	--	6.1	109	74	--
	--	--	--	5.8	110	74	--
	--	--	--	6.3	112	76	--
Average	--	--	--	6.5	120	81	77

*Based on the 70^{o}F strength of the parent fabric.

Table XII --- Concluded

TENSILE PROPERTIES OF WELDED JOINTS AT AMBIENT AND ELEVATED TEMPERATURES

Fabric Description	Temp (^oF)	Parent Fabric: Rupture Elong (%)	Parent Fabric: Rupture Load (lbs/in.)	Welded Joint Coupons: Rupture Elong (%)	Welded Joint Coupons: Rupture Load (lbs/in.)	Welded Joint Coupons: Joint Efficiency* (%)	Sewn Joint Coupons: Joint Efficiency* (%)
55x55/39x39 plain weave singly-drawn yarn	70	--	--	5.9	109	103	--
	--	--	--	5.8	110	104	--
	--	--	--	4.8	110	104	--
	--	--	--	6.1	110	104	--
	--	--	--	5.2	112	106	--
Average	--	4.4**	106**	5.6	110	104	99
	1000	--	--	5.2	98	98	--
	--	--	--	4.3	103	97	--
	--	--	--	4.9	96	91	--
	--	--	--	6.1	106	100	--
	--	--	--	6.1	106	100	--
Average	--	--	--	5.3	102	96	95
81 x 81 2 x 2 basket weave singly-drawn yarn	70	--	--	4.8	207	84	--
	--	--	--	5.3	214	87	--
	--	--	--	4.7	207	84	--
	--	--	--	5.0	222	90	--
	--	--	--	5.4	223	90	
Average	--	10.2	247	5.0	215	87	92
	1000	--	--	8.1	220	89	--
	--	--	--	4.9	200	81	--
	--	--	--	6.2	203	82	--
	--	--	--	6.0	204	83	--
	--	--	--	6.3	200	81	--
Average	--	--	--	6.3	205	83	67

*Based on the 70^oF strength of the parent fabric.
**Rupture properties of the 39 x 39 parent fabric.

Table XIII

TENSILE PROPERTIES OF WELDED AND SEWN JOINTS OF BUNDLE-DRAWN CHROMEL R FABRIC AT AMBIENT AND ELEVATED TEMPERATURES

Fabric Description	Parent Fabric			Welded Joint Coupons			Sewn Joint Coupons		
	Temp (°F)	Rupture Elong (%)	Rupture Load (lbs/in.)	Rupture Elong (%)	Rupture Load (lbs/in.)	Joint Eff (%)	Rupture Elong (%)	Rupture Load (lbs/in.)	Joint Eff (%)
80 x 81 2 x 2 basket weave	70	--	--	10.5	121	102	14.2	108	91
	--	--	--	10.2	117	99	14.2	110	93
	--	--	--	10.6	125	105	15.8	98	83
	--	--	--	10.0	107	90	14.3	104	88
	--	--	--	11.7	122	103	15.2	104	88
Average	--	11.3	118.5	10.6	118	100	14.7	105	89
	1000	--	--	7.4	95	100	11.0	74	78
	--	--	--	9.0	92	97	12.2	76	80
	--	--	--	10.1	99	105	11.2	92	97
	--	--	--	8.5	96	101	12.3	73	77
	--	--	--	6.6	72	76	13.0	70	74
Average	--	10.1	95.0	8.3	91	96*	11.9	77	81*

*Based on 1000°F strength of parent fabric.

Table XIV

TENSILE PROPERTIES OF CREASED, WELDED JOINTS
AT AMBIENT AND ELEVATED TEMPERATURES

Fabric Description	Temp (°F)	Rupture Elong (%)	Rupture Load (lbs/in.)	Joint Efficiency* (%)	Joint Strength Loss Due To Creasing** (%)
39 x 39 plain weave singly-drawn yarn	70	4.1	100	94	--
	--	4.4	89	84	--
	--	3.6	86	81	--
	--	4.4	93	88	--
	--	4.2	90	85	--
Average	--	4.1	92	87	5
	1000	4.8	93	88	--
	--	4.2	73	69	--
	--	4.4	91	86	--
	--	5.8	90	85	--
	--	4.9	70	66	--
Average	--	4.8	83	78	5
55 x 55 plain weave singly-drawn yarn	70	7.0	137	93	--
	--	7.0	147	100	--
	--	6.7	116	78	--
	--	6.9	141	95	--
	--	6.8	147	100	--
Average	--	6.9	138	93	6
	1000	5.7	125	84	--
	--	5.7	119	80	--
	--	6.2	123	83	--
	--	7.4	109	74	--
	--	8.6	137	93	--
Average	--	6.7	123	84	0

*Based on the 70°F strength of the parent, uncreased fabric.
**Based on the 70°F strength of welded, uncreased coupons.

Table XIV - - Concluded

TENSILE PROPERTIES OF CREASED, WELDED JOINTS
AT AMBIENT AND ELEVATED TEMPERATURES

Fabric Description	Temp (%)	Rupture Elong (%)	Rupture Load (lbs/in.)	Joint Efficiency* (%)	Joint Strength Loss Due To Creasing** (%)
55x55/39x39 plain weave singly-drawn yarn	70	6.2	104	98	--
	--	5.3	112	106	--
	--	5.5	107	101	--
	--	4.7	106	100	--
	--	5.6	106	100	--
Average	--	5.5	107	101	3
	1000	6.0	85	80	--
	--	6.9	104	98	--
	--	4.9	68	64	--
	--	4.8	78	74	--
	--	4.6	81	76	--
Average	--	5.4	83	78	19
81 x 81 2 x 2 basket weave singly-drawn yarn	70	5.2	245	99	--
	--	7.9	245	99	--
	--	5.2	217	88	--
	--	9.8	245	99	--
	--	8.5	235	95	--
Average	--	7.3	237	96	0
	1000	5.3	192	78	--
	--	5.3	190	77	--
	--	5.1	193	78	--
	--	6.8	206	83	--
Average	--	5.6	194	79	5

*Based on the 70°F strength of the parent, uncreased fabric.
**Based on the 70°F strength of the welded, uncreased coupons.

Table XV

TENSILE PROPERTIES OF CREASED, WELDED AND SEWN JOINTS OF BUNDLE-DRAWN CHROMEL R FABRIC AT AMBIENT AND ELEVATED TEMPERATURES

Fabric Description	Temp (°F)	Welded Joint Coupons				Sewn Joint Coupons			
		Rupture Elong (%)	Rupture Load (lbs/in.)	Joint Eff. (%)	Strength* Loss (%) Due to Creasing	Rupture Elong (%)	Rupture Load (lbs/in.)	Joint Eff. (%)	Strength* Loss Due To Creasing (%)
80 x 81	70	11.2	115	97	--	13.2	97	82	--
2 x 2	--	10.6	115	97	--	13.2	104	88	--
basket weave	--	9.9	116	98	--	13.3	86	73	--
	--	10.3	114	96	--	15.3	96	81	--
	--	10.3	113	95	--	16.4	108	91	--
Average	--	10.5	115	97	3*	14.3	98	83	7*
	1000	8.1	79	83	--	10.8	65	--	--
	--	8.2	77	81	--	12.0	68	--	--
	--	8.0	92	97	--	12.0	79	--	--
	--	9.5	95	100	--	12.9	78	--	--
	--	7.6	68	72	--	8.6	55	--	--
Average	--	8.3	82	86**	10*	11.3	69	73**	10*

*Based on the uncreased, welded, or sewn, coupon strength tested at the same temperature.

**Based on the parent fabric strength at 1000°F.

Table XVI

FOLDING ENDURANCE OF WELDED SEAMS

Fabric Description	Folding Endurance of Parent Fabric (cycles to failure)		Folding Endurance of Welded Joints (cycles to failure)	
	Warp	Filling	Warp (along seam)	Filling (across seam)
39 x 39	--	--	29	918
plain weave	--	--	100	660
singly-drawn	--	--	158	710
yarn	--	--	124	825
	--	--	235	708
Average	765	568	130	765
55 x 55	--	--	96	722
plain weave	--	--	90	806
singly-drawn	--	--	204	762
yarn	--	--	278	798
	--	--	120	755
Average	692	624	158	769
55x55/39x39	--	--	237	940
plain weave	--	--	148	962
singly-drawn	--	--	445	888
yarn	--	--	64	873
	--	--	140	943
Average	765	568	207	922
81 x 81	--	--	84	921
2 x 2 basket weave	--	--	82	1083
singly-drawn	--	--	75	922
yarn	--	--	108	1002
	--	--	104	1037
Average	968	992	91	993

Table XVII

FOLDING ENDURANCE OF WELDED AND SEWN SEAMS
OF BUNDLE-DRAWN CHROMEL R FABRIC

Fabric Description	Folding Endurance of Parent Fabric (cycles to failure)		Folding Endurance of Welded Joints (cycles to failure)		Folding Endurance of Sewn Joints (cycles to failure)	
	Warp	Fill	Warp (along seam)	Fill (across seam)	Warp (along seam)	Fill (across seam)
80 x 81	--	--	85	319	866	1433
2 x 2	--	--	73	288	847	1368
basket weave	--	--	80	305	1121	1207
	--	--	72	321	762	1238
	--	--	66	308	777	--
Average	234	287	76	309	875	1312

As previously noted, the only parent fabric tested at 1000°F under this contract was the 80 x 81 bundle-drawn filament fabric. The joint efficiencies for these fabric joint coupons are based on the parent fabric average strength at 1000°F. The spot welded coupons show only a 4% joint efficiency loss at 1000°F. The joint efficiencies for the other welded fabrics tested at 1000°F were calculated based on the room temperature average strength of the parent fabric, which indicate an apparent tensile strength loss of welded joint coupons, ranging from 5% to 18%. Without further test data it cannot be determined what portion of this strength loss is due to temperature degradation of the fabric, variation of parent fabric strength, or what portion is strength degradation attributable to the fabric joining processes.

However, analysis of the metallurgical characteristics of the alloy and cast structure of the welds does not indicate that the strength of the weld nuggets should be significantly affected by the 1000°F temperature. Also, published data on temperature tests of Chromel R 0.5 mil filament yarns and fabrics indicate a strength loss of only 2% for the particular yarn and parent fabric tested (the 80 x 81 bundle-drawn filament parent fabric, tested under this contract lost 20% of its room temperature strength at 1000°F).

The only sewn coupons tested under this contract, at 1000°F using the 80 x 81 uncreased fabric, indicated a strength loss of 19% based on the parent fabric average strength at 1000°F. FRL[5] data for the sewn fabric coupons tested under another contract indicated an even larger strength loss for the 81 x 81 sewn coupons, although all the thinner sewn fabric coupon efficiencies were comparable to welded coupon efficiencies. The relatively large strength losses for the sewn coupons of the 80 x 81 and 81 x 81 fabrics may have resulted from a population of abnormal sewn coupons, or may be characteristic of sewn joints in the heavier fabrics.

Sharp edge creasing along the line of spot welded joints, on the single-drawn fabrics, caused only a relatively small reduction in joint strength (0% to 6%), at all temperatures, with the exception of the 55 x 55 fabric joined to 39 x 39 fabric when tested at 1000°F. In the latter case an unexplainable, apparent strength loss of 19% occurred. Sharp edge creasing of the 80 x 81 bundle-drawn fabric produced strength losses of 7% at room temperature and 10% at 1000°F.

Folding endurance of the spot welded coupons, when the single layer of fabric was folded along the line of the joint welds, was only 17% to 28% as good as the parent fabric. Folding endurance, when folded across (perpendicular to) the spot weld joint rows was as good, or better than, the parent fabric (these coupons flexed two layers of fabric).

The tensile strength of the sewn joints, after creasing, was tested only on the 80 x 81 bundle-drawn fabric. The joint efficiencies were surprisingly low, especially at high temperature, since the folding endurance of these joints proved to be excellent. However, the relatively low joint strengths for the creased sewn coupons of this fabric was also characteristic of the uncreased sewn coupons of the same fabric.

The folding endurance of the sewn coupons of the 80 x 81 fabric was excellent, both along and across the seam. However, all four layers of the fabric in the sewn joints were flexed in each test. Folding endurance along the seam was 370% greater than the parent fabric and 460% greater across the seam. As discussed below, the sewing in the joint caused little degradation of folding endurance relative to the parent fabric. Unfortunately, it was not possible to test both the welded and sewn coupons in a similar manner, therefore only generalized conclusions can be drawn from the test data. Fabric Research Laboratories, Inc., observed that:

> Although the sewn seams appear to have a much higher folding endurance than either the welded seams or the unseamed fabric, it should be noted that the test made on the sewn seams are not strictly comparable to those performed on the unseamed fabric or on the welded seams. Each sewn seam is four layers of fabric thick which appreciably changes the radius of curvature over which each layer is bent. Consequently a series of measurements were made on unseamed fabric mounted similarly to the sewn seam specimens. The specimens tested in the warp direction, analagous to testing along a seam, were mounted with three additional layers of untensioned fabric protruding from the bottom jaw on one side of the tensioned specimen. To simulate across the seam tests, four strips, tensioned in the filling direction, were mounted between the top and bottom jaws. As in the tests on sewn seams, a 0.05 inch jaw opening was used. The results are given in Table XVIII. This data shows that the folding endurance of sewn seams is equivalent to that of unseamed fabric tested similarly. It further suggests that the folding endurance increases with the radius of curvature of the surface over which a specimen is bent. This result, although not unexpected, serves to accentuate the low folding endurance obtained along the welded seams, since in this test also the radius of curvature is greater to one side of the centerline position by one fabric thickness than in the test on unseamed fabric.

Table XVIII

FOLDING ENDURANCE OF BUNDLE-DRAWN
CHROMEL R PARENT FABRIC MOUNTED SIMILARLY TO SEWN SEAMS

	Folding Endurance (cycles to failure)	
	Warp	Filling
	1194	1795
	706	1476
	1101	1663
	644	1312
Average	911	1561

Probability Analysis

A probability analysis was performed using the qualification coupon data tabulated in Tables IX, X, and XI. The parent fabric coupon test data used to develop the FRL® parent fabric average strengths was not available; therefore, the AGC parent fabric variance test data (Table IX) was used to compute deviations. However, for consistency of analysis in this report the FRL® parent fabric average rupture loads were used.

Method of Analysis

For each coupon configuration the following two statements are made:

1. The average weld strength exceeds Y% of the average parent strength at the 90% confidence level (Table XX).

2. The average weld strength exceeds 85% of the average parent strength at a confidence level of W (Table XXI).

The computation consists of finding the mean, $\overline{X}$, and variance of each population to be compared (Table XIX). Then the following are solved:

A. For Statement 1:

Let average weld strength be $\overline{X}_1$.

Let standard deviation of the mean be $S_{\overline{X}_1}$

Find t = 1.533* for 90% confidence and 4 degrees of freedom.

Let the average parent m terial strength be X_2.

Solve $$\frac{\overline{X}_1 - X}{S_{\overline{X}}} = t = 1.533 \text{ for } X$$

and $$\frac{X}{X_2} = (.01)\ (Y)$$

B. For Statement 2:

Compute $$\frac{\overline{X}_1 - .85\,(\overline{X}_2)}{S_{\overline{X}}} = Z$$

Use "t" Table* to determine W from the "t" value Z.

*Statistical "t" variable is tabulated for various confidence levels and degrees of freedom in statistics handbooks.

Table XIX

STANDARD DEVIATIONS

Fabric Description	Average Rupture Loads (lbs/in.)			
	Parent Fabric	2 Layer Spot Weld	4 Layer Spot Weld	2 Layer Sewn
39 x 39 singly-drawn	106	101.8	105	--
55 x 55 singly-drawn	148	148.2	141.4	--
81 x 81 singly-drawn	247	224.2	228.8	--
80 x 81 bundle-drawn	118.5	115.8	115	103
	Standard Deviation			
39 x 39 singly-drawn	4.324	5.070	3.00	--
55 x 55 singly-drawn	4.764	8.012	8.050	--
81 x 81 singly-drawn	6.693	17.02	9.011	--
80 x 81 bundle-drawn	3.361	4.025	4.472	13.096
	Standard Deviation of the Mean $S_{\bar{X}}$			
39 x 39 singly-drawn	1.934	2.264	1.341	--
55 x 55 singly-drawn	2.13	3.583	3.600	--
81 x 81 singly-drawn	2.993	7.612	4.030	--
80 x 81 bundle-drawn	1.503	1.800	2.00	5.857

Table XX

JOINT EFFICIENCIES VS. CONFIDENCE LEVEL

Fabric Description	Values of Y(1)		
	Coupon Joint Configuration		
	2 Layer Spot Welded	4 Layer Spot Welded	2 Layer Sewn
39 x 39 singly-drawn	92.7	96.2	--
55 x 55 singly-drawn	97.4	91.8	--
81 x 81 singly-drawn	86.0 (2)	90.1 (2)	--
80 x 81 bundle-drawn	95.4	94.4	79.3 (3)

(1) The average welded coupon strength exceeds Y percent of the average parent fabric strength at the 90% confidence level.

(2) The FRL® average of 247 p.p.i. for the parent fabric was higher than any individuals of the coupons tested at AGC. The variance of the 2 layer spot weld was much higher than for any other fabric type.

(3) The average was low and the variance high.

Table XXI

CONFIDENCE LEVELS VS. JOINT EFFICIENCY

Fabric Description	Values of W(1)		
	Coupon Joint Configuration		
	2 Layer Spot Welded	4 Layer Spot Welded	2 Layer Sewn
39 x 39 singly-drawn	>99.5%	>99.9%	--
55 x 55 singly-drawn	>99.5%	99.3%	--
81 x 81 singly-drawn	93.0%	99.5%	--
80 x 81 bundle-drawn	99.95%	99.9%	64%

(1) W is the confidence level at which the average weld strength exceeds 85% of the average parent fabric strength.

3.8 RELATIVE MERITS OF VARIOUS JOINING METHODS

Various methods of producing efficient, flexible structural joints in ultra-fine filament metal fabrics were previously investigated under contract AF33(657)-10252 and documented in report number AFML-TR-67-310. Development and evaluation of sewn joints is reported in the Air Force Material Laboratory report AFML-TR-67-267, and some limited data is presented in previous sections of this report.

Some of the methods investigated which were not previously discussed in this report included exobrazing, interrupted seam welding, continuous seam welding, infra-red brazing, induction brazing, resistance brazing, electron beam welding, adhesive bonding, and integral weaving. None of these methods produced a structurally efficient, flexible, joint in metal fabric structures designed to operate at high temperatures. Currently, it seems that only the micro-spot welding and metal yarn sewn methods can produce efficient and practical joints.

The fabrication and testing of complex pressure stabilized metal fabric structural shapes, joined by micro-spot welds, demonstrated the practicality of this joining method as reported in AFML-TR-67-310. Up to five layers of 0.012 inch thick fabric, involving intersecting seams, were tested under combined loading at elevated temperature. The process requires skilled operators and meticulous process control. The existing experimental welder configuration limits enclosed fabric structural shapes to diameters greater than 6.5 inches, or 20 inches in circumference. Redesign of the lower welder head could conceivably permit joining fabric, of enclosed configurations, in diameters of less than one inch.

Tests conducted to date indicated that the spot welded joints are very flexible, produce high joint efficiencies and are relatively unaffected by creasing or temperatures in excess of 1000°F. Folding endurance is low relative to the parent fabric and could possibly produce a design restraint for a high density packaged structure exposed to a large number of sharp edge folding cycles. However, layers of flexible padding material, applied at the welded joints during packaging, would increase the folding radius and folding endurance greatly.

The sewn joints appear to produce joint efficiencies which are in most cases comparable to those of the spot welded joints. The sewn joints tested were twice as thick and twice as wide as the welded joints, and therefore much less flexible. The inter-folded LSc type joint used on the sewn test coupon could not be used at the intersection of seams No data is known to be available to indicate what joint efficiencies would result if some type of suitable sewn seam intersection were devised. The sewn seam sharp edge crease strength is approximately as good as that of the welded seams and the folding endurance is excellent.

The restraints imposed upon enclosed structural envelope sizes by the sewn joint process is unknown. However, it appears that the minimum fabric circumference that could currently be seamed is that of the base of the smallest standard sewing machine.

SECTION IV

REFERENCES

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13. ABSTRACT

Many advanced systems require flexible, high-strength structural materials capable of operating at environmental temperatures up to 2000°F in order to efficiently perform the required system missions. This especially true of inflatable, pressure stabilized structures for space and reentry applications, and non-flammable components and systems for manned space flight. Highly efficient metal fabrics have been developed to satisfy these material requirements but no efficient method of joining these materials into flexible structural configuration was available until a unique automatic spot-welder for producing flexible joints in fabrics was developed by ~~the~~ Aerojet-General Corporation under a previous contract for the Air Force Materials Laboratory. The work reported herein explored the capabilities of this joining technique for application to a wide variety of nickel-chrome structural fabric styles, and is probably equally as efficient for fabrics woven from other steel alloys. Good, flexible, structural joint properties were found up to the 1000°F limit of the test temperatures.

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